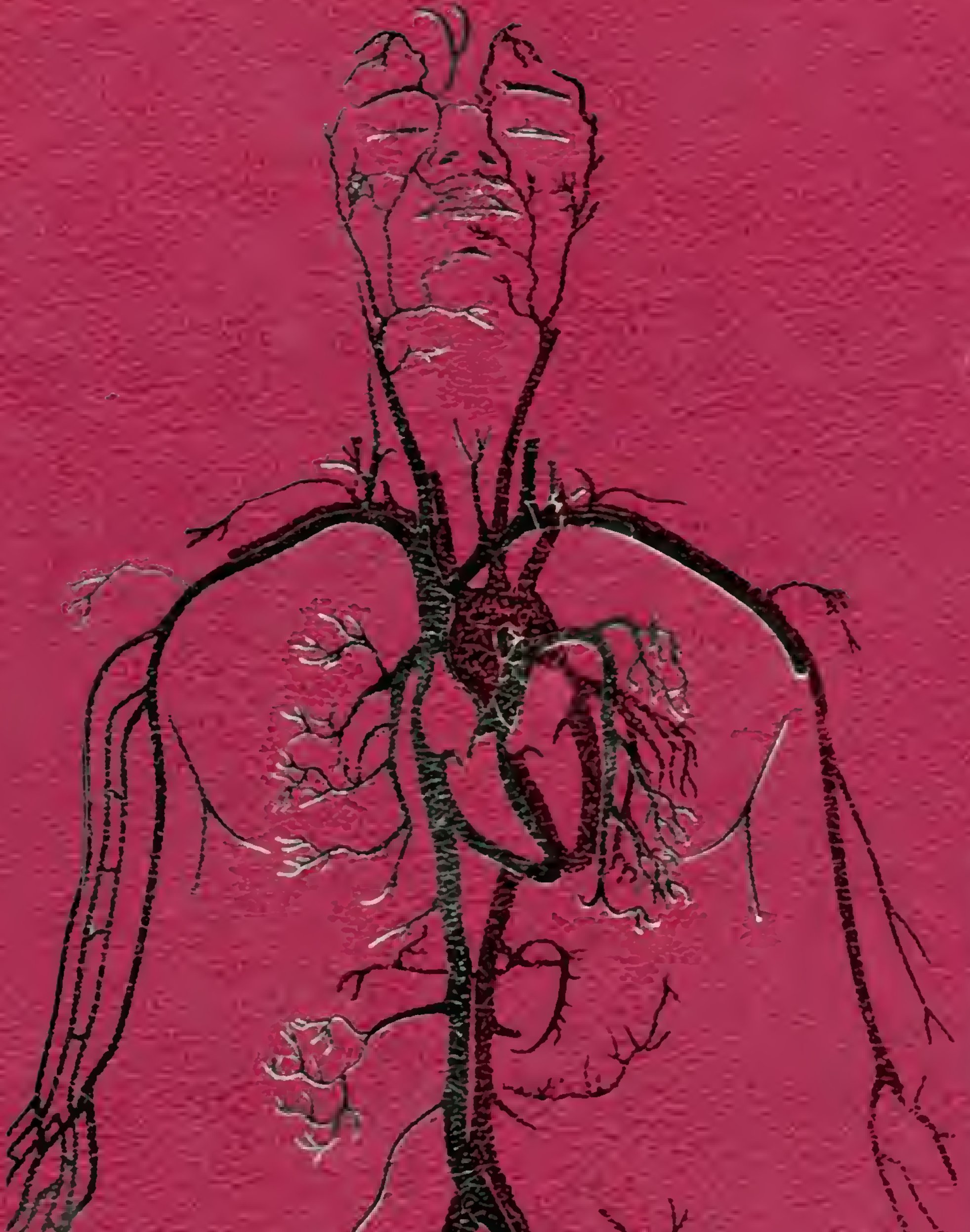

HUMAN ANATOMY

VOLUME 3

EDUCATIONAL LITERATURE
For the students of higher medical educational establishments

HUMAN ANATOMY

In three volumes

Volume III

Edited by
prof. V.G. KOVESHNIKOV

Recommended by the Central methodical committee on higher medical education of MPH Ukraine as a textbook for the students of higher medical educational establishments of IV level of accreditation.

Lugansk, 2009

ББК 28.860
A 64

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SHORTENINGS KEY:

a.	– arteria	– artery	mm.	– musculi	– muscles
aa.	– arterie	– arteries	n.	– nervus	– nerve
art.	– articulatio	– joint	nn.	– nervi	– nerves
artt.	– articulationes	– joints	nucl.	– nucleus	nucleus
for.	– foramen	– opening	nucll.	– nuclei	– nuclei
forr.	– foramina	– openings	r.	– ramus	– branch
gangl.	– ganglion	– ganglion	r.r.	– rami	– branches
gangll.	– ganglia	– ganglia	sul.	sulcus	– sulcus
lam.	– lamina	– plate	sull.	– sulci	– sulci
lamm.	– laminae	plates	sut.	– sutura	– sutura
lig.	– ligamentum	– ligament	sutt.	– suturae	– suturae
ligg.	– ligamenta	– ligaments	v.	– vena	– vein
m.	– musculus	– muscle	vv.	– venae	– veins

A 64 Human Anatomy. In three volumes. Volume 3 / Edited by V.G. Koveshnikov. – Lugansk: LTD «Virtualnaya realnost», 2009. – 384 p.

ISBN 966-8526-54-6
ISBN 978-966-492-074-9 (Vol. 3)

ББК 28.860

The textbook is devoted to a fundamental part of medicine — anatomy.

The textbook is based on the International Anatomical Nomenclature (San Paulo, 1997) and optimized to the credit-module system. The third volume contains the information on the nervous, the cardiovascular and the lymphatic systems.

The book is aimed at students and instructors of higher medical educational establishments of the IV level of accreditation.

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PREFACE

The third volume of textbook systematically presents the material on the nervous, the cardiovascular and the lymphatic systems according to the current curriculum for medical universities (2005). In addition to providing general anatomical information, each section of the textbook includes material on the development, variations, and anomalies of organs and systems. The textbook also emphasizes clinical applications of the presented information. We paid particular attention to the substantiation of general principles in the study of anatomy: the correlation between the structure and function, the integrity of the organism, and the unity of the organism with its external environment.

Each section ends with practice questions, which allow students to self-evaluate their progress. In preparing this textbook, we have been guided by the pedagogical expertise of many Ukrainian scientists-anatomists who became the coauthors of this work (Bobrick I.I., Kyiv; Voloshin M.A., Zaporizzha; Golovatzky A.S., Uzhgorod; Ilyin I.I., Odesa; Kiryakulov G.S., Donetsk; Koveshnikov V.G., Lugansk; Kozlov V.O., Dnipropetrovsk; Kostylenko Yu.P., Poltava; Luzin V.I., Lugansk; Lupyr V.M., Kharkiv; Pikalyuk V.S., Symferopol; Romensky O.Y., Vinnitsa; Sykora V.Z., Sumi; Fedonyuk Y.I., Ternopil; Shutka B.V., Ivano-Frankivsk. All coauthors followed a uniform representational style depicting a modern scientific state of the subject in a given unit of the textbook.

In the textbook, we used new anatomical terminology, approved by FCAT (Sax Paulo, 1997). Ukrainian equivalents of the terms are presented in accordance with the book «International Anatomical Nomenclature» edited by Professor I.I. Bobryck and Professor V.G. Koveshnikov (Kyiv, 2001).

Illustrations were borrowed from the manuals and textbooks accompanied by the authors' additions and revisions. The majority of the drawings made from the specimens are original.

Professor V.G. Koveshnikov

NERVOUS SYSTEM

INTRODUCTION

Nervous system — the system of *integration and regulation*

The chief purpose of the nervous system is to maintain communication between the organism and the environment and to control functioning of the organs and systems of the organism *per se*.

The animal organisms receive data on environment in the form of various stimuli accepted by the sensory organs. The receptors transform the energy into the nervous impulses transmitted by the afferent nerve fibers to the CNS for processing and generation of the appropriate response. The outcome impulses reach the respective effectors to form the body response. This so-called external function of the nervous system provides communication and adaptation of the organism to the continuously changing environment.

Another important function of the NS is the internal function, which constitutes coordination of organs and systems' activities. This function provides integration of separate parts of the organism and homeostasis maintenance. The internal function is tightly connected with the humoral regulation and thus the nervous and endocrine systems form a functional unit.

Nervous system subdivisions

The nervous system has two major subdivisions: the central nervous system (CNS), which consists of the brain and spinal cord and the peripheral nervous system (PNS), which comprises the cranial and spinal nerves and the vegetative ganglia and plexuses.

Depending on the area effected, the nervous system is subdivided into somatic and vegetative (autonomic) divisions. Somatic division supplies the *soma* organs (skin, sensory organs, skeletal muscles, bones and joints) and thus performs external function of the NS. Vegetative division in turn supplies the *viscera*, heart, blood vessels, smooth muscles and glands. Vegetative division also has two subdivisions: sympathetic and parasympathetic, which possess opposite effects on the organism. The vegetative division performs the internal function.

Neuron — the structural functional unit of the nervous system

The structural functional unit, which provides physiological properties to CNS, is a neuron (neurocyte). The neurons are surrounded by supportive and nourishing cells that form the framework called neuroglia.

The neurons possess a unique feature — generation and transmission of nerve impulses in response to stimu-

lus (mechanical, electrical, chemical etc.). Specialized contacts between nerve cells (synapses) allow transmission of the signals to other neurons.

Approximate counting put the number neurons at 10 to 100 billion (10^{11}) cells of various shapes and sizes (5 to 135 μm).

The neuron consists of the body (soma), which comprises the nucleus and surrounding cytoplasm called **perikaryon**. Numerous cytoplasmatic processes transmit the nerve impulses. Depending on processes number the neurons are subdivided into multipolar, bipolar and pseudounipolar (unipolar).

Multipolar neurons

Neurons of this type have numerous *dendrites* and single *axon*:

- *dendrites* (from Greek '**dendron**' – a tree) are short numerous arborizing processes that never leave CNS limits; they receive signals from other neurons and transmit them to neuron's *soma*;
- *axon* (from Greek '**axon**' – axis) is a single long process, which may leave CNS limits. These processes transmit the signal from the *soma* to respective organ. Axon's length varies from 1 mm up to 1 m.

Multipolar neurons feature variety of shapes and sizes.

Bipolar and pseudounipolar neurons

Bipolar neurons have two processes that run from opposite cell poles. Most of bipolar neurons in evolution progress as seen in developing embryo transform into pseudounipolar as the result of merging of separate processes. These cells seem to have one process, which at a short distance branches like a T to form two processes (fibers) – peripheral and central:

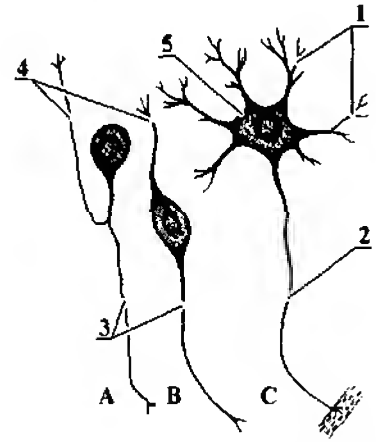

Fig. 1. Structure of neurons A – pseudounipolar neuron, B – bipolar neuron, C – multipolar neuron 1 – dendrites, 2 – axon, 3 – peripheral process, 4 – central process, 5 – body of neuron.

- the *peripheral fiber* (equal to dendrite) runs to periphery and ends with receptor. It conducts the signal to the soma;
- the *central fiber* (equal to axon) conducts impulse from the soma and thus runs to CNS.

Some areas such as retina, sensory ganglia of VIII cranial nerves and olfactory region of nasal mucosa retain true bipolar neurons.

Functional classes of neurons

From functional point of view sensory, motor and association (interneurons) are distinguishable:

- *sensory (afferent)*[1] *or reception* neurons reside mainly in sensory ganglia of spinal and cranial nerves (outside CNS); they are pseudounipolar neurons (sometimes unipolar);
- *motor (efferent) neurons* transmit impulses to peripheral organs (e.g. muscles and glands). They are multipolar neurons i.e. their bodies reside within CNS or vegetative ganglia while processes mostly leave CNS limits;
- *interneurons (association neurons)* transmit signals only within CNS. They link sensory and motor neurons and belong to intermediate computing network.

Sensory (input) and motor (output) neurons count several millions cells and interneurons constitute 99.9 % of CNS neurons. Interneurons thus play key role in data processing and determine complexity of structure and functioning of CNS.

Receptors

Receptors are the specialized nerve terminations of sensory neurons located in various tissues, where stimulus transforms into nerve impulse. Depending on location, the following types of receptors are distinguishable:

- **exteroceptors**, which reside in skin, mucous membranes and specialized tunics of the sensory organs (retina, membranous labyrinth etc.). They receive stimuli from environment. This type of sensitivity is called exteroceptive (pain, temperature, tactile, sight, olfactory and taste);
- **proprioceptors** are the sensitive nerve terminals in muscles, tendons, fasciae, periosteum and joint capsules). This type of sensitivity is called proprioceptive. Proprioceptive impulses are responsible for spatial orientation and feeling of both active and passive movements;
- **interoceptors** are located in the viscera (stomach, heart, lungs, liver etc.) and blood vessels. This type of sensitivity is called interoceptive.

Synapses

Neurons form vast networks with the help of processes that contact to form unique type of connections called synapses. Neuron's processes may contact other neuron's soma or processes forming thus various types of synapses. Typically, one neuron may possess 1000 to 10000 synapses for continuous evaluation of the incoming signals to form output impulses of appropriate frequency. There are two major types of synapses: excitatory and inhibitory. Total number of CNS related synapses is approximately 10^{14} (100 billion).

CNS language – electrical and chemical

Stimulus intensity encoding is provided by frequency and duration of electric impulses. Nerve impulse causes release chemical substances (neurotransmitters) like acetylcholine, norepinephrine, dopamine, etc into synaptic cleft. They act on post-

[1] – afferens (Lat.) – bringing in

synaptic neuron changing its electric activity thus sending certain data. Some synapses possess direct electrical data transmission.

Myelin sheath

Most of the axons feature especially thick whitish sheath formed of fat-like substance – myelin. Such fibers are called myelinated. Myelin serves as insulation and promotes faster impulse transmission. Neuron's bodies and dendrites are devoid of myelin.

White and grey matters

Visual examination reveals in brain and spinal cord two well distinguishable areas called the white matter and the grey matter.

The *grey matter*, **substantia grisea** represent the areas where myelin-devoid neurons' bodies concentrate. The grey matter forms the *cortex of brain*, **cortex cerebri**, the *cortex of cerebellum*, **cortex cerebelli**, the *nuclei* (Lat. Id.) of the brain and spinal cord and the *columns*, **columnae** of the spinal cord.

The *white matter*, **substantia alba** corresponds to the areas that contain myelinated neurons' processes. Whit substance forms the *fibers*, **fibrae** and *tracts*, **tractus**.

Reflex principle of CNS functioning Works of I.N. Sechenov, C. Sherrington and I.P. Pavlov

Basic principle of the entire nervous system functioning is the reflex (from Lat. '**reflexus**' – reflected). I.N. Sechenov in his 'Brain reflexes' demonstrated that nervous system functions basing on various reflexes. This principle is universal for the entire nervous system and extends onto psychic activities. In the beginning of the 20th century the famous English physiologist C. Sherrington discovered laws of reflex activities of the spinal cord and thus put the basis under distinguishing of nervous system units.

The concept of reflex principle reached its maximum development in classic works of I.P. Pavlov. In addition to congenital unconditioned reflexes, he discovered quite a new type of conditioned reflexes acquired by animals and humans in the process of individual development. Anatomical substrate for the reflex is the reflex arc.

Practice questions

1. What is the chief function of the nervous system?
2. Name divisions of the nervous system
3. What is the structural functional unit of the nervous system?
4. What elements are distinguishable in the multipolar neuron?
5. Give characteristic of processes branching in pseudounipolar neurons.
6. Describe functional classification of the neurons.
7. Name types of receptors related to their location.
8. Give definition of the synapses.
9. How do the NS elements communicate?
10. Name main differences between grey and white substances
11. What is the basic principle of NS functioning

EVOLUTION OF THE NERVOUS SYSTEM

1. Nervous system in invertebrates

Origination of the nervous system

Unicells and inferior metaphytes have no distinguishable nervous system. Initially, any cell is able to accept stimulus and produce a response to it. As the animals develop several cell layers that form the body, the superficial and deep layers appeared under different conditions in regard to environmental stimuli. Impulse transmission from superficial to deeper layers became a concern. In evolution process, first nerve cells derive from the external epithelial lining of the animal's body (ectoderm). Primitive nervous system first appears in Coelenterata (hydras, jellyfish etc.). Prototypes for the nervous cells were single ectodermic cells, which developed extra sensibility to environmental changes. Their cytoplasm processes allowed transmission of the signals to muscle-like (myoid) cells, which acquired contraction ability.

Single-neuron stimulus transmission

It is quite possible that first system to appear at early evolution stages was the single-neuron transmission system. Nerve cells located in the ectoderm and thus in contact with ambient reach the deeper myoid cells with their processes. In any case, stimulation of the nerve cell results in predictable reaction – muscle fibers contraction and animal's reaction.

Origination of double-neuron chain

Evolution of the nervous system resulted in increase of nervous cells number and differentiation of sensory and motor neurons. The neurons form numerous connections and join into vast network below ectoderm. This type of NS is called diffuse or network-type. Neurons located in ectodermic epithelial layer (sensory) form contacts (synapses) with sub-epithelial neurons (motor), which in turn contact the muscular or glandular cells located within the body. Thus, the double-neuron (monosynaptic) connections provide advanced data processing.

Origination of association neurons

As evolution progresses, the nervous cells concentrate in certain places of the body to form nodes (ganglia), which are segmental nervous centers. This type of NS is called ganglion-type. Association neurons transmit signals from one neuron to another. Thus, at this evolution stage three types of neurons are distinguishable: sensory, association and motor. Ir this case, sensory (afferent) neurons as a rule lose direct connections with motor (efferent) neurons. Association neurons take over communication functions providing thus complex data processing and integration of NS.

At this evolution stage, the annelids and arthropods exhibit intensive development of neurons in the cranial end of the body leading to formation of larger ganglia. Insects feature epipharyngeal ganglion, developed distinctly better than in other species, which gives certain grounds to identify it as brain.

2. Nervous system in chordates

Origination of tubular nervous system

Chordates possess quite different type of NS compared to invertebrates. Neurons concentrate in the walls of tube that runs along the dorsal body wall. The anterior dilated end of the tube represents the brain while the body-related portion forms the spinal cord.

Tubular nervous system probably originates from longitudinal ectodermic plate in chordates progenitors. This plate lies dorsally and consists of sensory epithelium. Further, it incorporates into a body to form neural groove open dorsally. The groove edges eventually fuse to form a tube. The lancelet possesses the most primitive CNS as it lacks brain[1] and features incompletely fused neural tube.

Segmentation of the neural tube

The body of chordates features metameric structure therefore the neural tube has distinct segments also distinguishable in superior vertebrates. Each body segment is related to respective neural tube segment and the spinal cord consists of identical segments. Number of neural segments is equal to number of body segments. The ventral portion of the tube gives rise to motor neurons, which form the ventral roots supplying the muscles. The dorsal portion in turn gives rise to sensory neurons, which form the dorsal roots related to the integuments. In all vertebrates beginning from cyclostomes, the sensory neurons leave the spinal cord to form spinal ganglia visible as a bulge on the dorsal root. In lampreys, both roots run as separate nerves while in fish and other vertebrates the roots join to form mixed spinal nerve. The spinal nerves originate from the respective neural segment and correspond to the body segments.

Origination of the brain

The cyclostomes are the first to develop a brain – a primitive organ, which appears as a small extension on the cranial end of neural tube. The brain in cyclostomes has several distinguishable compartments.

Fish also possess underdeveloped brain yet all brain compartments featured by superior vertebrates are distinguishable:

1) the *forebrain*, **prosencephalon** comprising telencephalon and diencephalon;

2) the *midbrain*, **mesencephalon**;

[1] – actually, the cranial end of the neural tube in lancelet has a small dilation considered by some authors as brain

3) the *rhombencephalon* (Lat. Id.) comprising metencephalon and myelencephalon.

The *forebrain in fish* as a rule features underdeveloped hemispheres but well developed olfactory parts. This compartment has well differentiated nuclei of the corpus striatum, the pineal and the pituitary glands. The midbrain is best developed compared to other compartments and contains vision and auditory centers. Structures within the phombencephalon are represented with the cerebellum and the medulla oblongata. The latter develops vital regulatory centers as respiratory, circulatory and digestive (the vagus nerve nuclei).

Differentiation of the brain in terraneous vertebrates

In amphibians, most significant changes to the brain occur in the telencephalon. The hemispheres undergo considerable development due to the nuclei of corpus striatum. The olfactory bulbs and the midbrain are also well developed.

The reptiles exhibit further development of the diencephalon (namely the thalamus) which has separate sensory nuclei. The hemispheres of the telencephalon are represented with the nuclei of corpus striatum, which control the animal's movements. The reptiles however feature better-developed *archicortex* (Lat. Id.) which is vestigial in amphibians. The archicortex in reptiles resides in the portion of hemisphere, which corresponds to the hippocampus in superior vertebrates. Moreover, the lateral surface of hemisphere appears to contain several primordias of the *neocortex* (Lat. Id.).

Telencephalon in birds is larger than in reptiles, yet the cerebral cortex is underdeveloped as well and the hemispheres are represented with the nuclei of corpus striatum.

Evolution of the brain in mammals

In mammals, development of neocortex appears to take a leading part in the entire brain evolution process, which in turn results in development of hemispheres of telencephalon and especially the neocortex. In all other vertebrates, the hemispheres consist of the nuclei of corpus striatum that are responsible for instinctive behavior. In mammals, the brain cortex features higher regulatory centers for important functions of the organism – visual, auditory, tactile, etc. and motor centers for voluntary movements of skeletal muscles. Primary olfactory portions of the hemispheres lag behind the rest of compartments and move ventrally and deeper into the telencephalon. Those portions are represented with the olfactory bulbs, olfactory tracts and related *paleocortex* (Lat. Id.) and *archicortex* (Lat. Id.) of the hippocampus.

In inferior mammals, surface of the hemispheres is smooth for lack of sulci and gyri. The superior species in turn develop numerous gyri delimited by sulci that give furrowed look to hemispheres. The sulci and gyri are quite expressed in hoofed animals, carniv-

ora, cetaceans and primates. Neocortex becomes the base of conditioned-reflex activities that originate from experience. Also neocortex acquires associative areas responsible for intellectual activities.

Because of intensive growth of the cortex, the white matter and the corpus callosum that joins the hemispheres also exhibit intensive development. The **hemispheres** cover underlying compartments of the brain and therefore the neocortex has another name **pallium** (the cloak).

The cavity of neural tube in mammals transforms into the ventricles of brain and the central canal of the spinal cord.

Hierarchical arrangement of the brain compartments

The fundamental point of brain evolution in vertebrates constitutes origination of new structures with every next stage of evolution but not replacement of the older structures with new. Studying the brain, one should always keep in mind that the central nervous system of the superior vertebrates and the humans comprise both old and relatively new brain compartments. The new compartments develop later yet they feature functional domination over the old ones. The newest among all compartments is the neocortex that reaches maximum development in humans. The neocortex acquires superior regulatory centers that subordinate underlying compartments. This can be determined as corticalization of cerebral functions. Therefore, the CNS features hierarchical arrangement that provides most effective employment of superior brain compartments by committing data processing and precise computations to underlying compartments with loopback principle featured. Due to interrelations system, the cortex and subcortical regulatory centers communicate continuously and thus function as single whole.

3. Features of the human brain

In evolution process, weight of the brain enlarged due to continuous increase of neurons number. Human brain is one of the largest compared to other mammals. Larger animals possess larger brain. So human brain weighs 1400 grams, dolphin brain – 1800 grams, elephant brain – 5200 grams and in whales – 7000 grams.

Relative brain weight quotient (brain mass divided by body mass) is larger in small mammals. In humans, the quotient is lower than in some small primates and some other animals. In order to exclude body weight influence on brain weight, the 'square weight index' is calculated as quotient of absolute and relative weight values. This index puts the humans into leading place among the rest of animals (32.0). In elephant, the index equals 9.62, in subhuman primates – up to 7.35, in dolphins – 6.72 and in carnivora – 1.14 etc.

Humans feature considerable domination of brain over the spinal cord and within the brain – domination of telencephalon over the rest of compartments. Another feature of hu-

man brain is well-developed frontal lobe, which is generally responsible for behavior of individual. In superior apes, the frontal lobe occupies 16% of the entire hemisphere area and in humans – up to 30%. Alongside with this, the cerebral cortex constitutes 40% of the entire hemispheres volume and houses about 70% of all CNS related neurons. Surfaces of hemispheres have numerous sulci and fissures that delimit numerous gyri.

Functional features of the cerebral cortex provide possibility of full possession of abstract thinking, which in turn provides the base for speech functions. This is the key feature that makes the human brain outstanding among the rest of animals.

Do intellectual abilities depend on brain weight? The answer to the question is strictly negative because brain weight in humans features wide variety from individual to individual and depends on many factors.

Development of a certain intellectual level primarily depends on physiological and biochemical processes that run in the cells of nervous system.

With the average weight values of 1300-1400 grams, brain weight even in prominent individuals ranges from 2200 to 1000 grams. For example, Byron's brain weighed 2238 grams, Turgenev's brain – 2012 grams, Cuvier's brain – 1861 grams, Pavlov's brain – 1653 grams, Pavlov's brain – 1653 grams, Borodin's brain – 1325 grams, Whitman's brain – 1282 and Anatole France's brain – 1017 grams. In the end of XIX century, Moscow anatomist D.M. Zernov proved that brain structure does not feature racial differences. Structural variations in gyri and brain weight depend solely on individual features influenced by various factors.

DEVELOPMENT OF CNS IN HUMANS

Formation of neural tube from ectoderm

CNS arises on early stages of embryo development from the external embryonic plate. At the 19th day of embryo development, the neural plate detaches from the dorsal surface of the ectoderm (fig. 2). Very soon, the neural plate gives rise to neural groove, which becomes the base of future CNS.

At the 4th week of development, intensive cell division leads to incorporation of the neural groove into the mesoderm; its edges fuse at midline thus forming the neural tube. Initially, the neural tube is open and has anterior and posterior openings – the neuropores that close sooner after.

Formation of neural crest

Before fusion, the edges of neural groove give rise to lateral cell masses

that run along the tube. Somewhat later, these masses develop into paired neural crests that undergo segmentation and give rise to spinal ganglia and the ganglia of cranial nerves. The ganglia comprise the bipolar neurons that further transform into pseudounipolar neurons.

Apart from this, some cells from the neural crests give rise to autonomic ganglia.

Differentiation of the neural tube

In the beginning, the neural tube is quite thin and consists of some layers of undifferentiated cells that further differentiate into neuroblasts that give rise to neurons and into spongioblasts that give rise to neuroglia and ependyma.

Neuroblasts exhibit intensive growth, which results in thickening of neural tube wall and gradual decrease of its density. At the end of the fourth week, the cranial end develops three

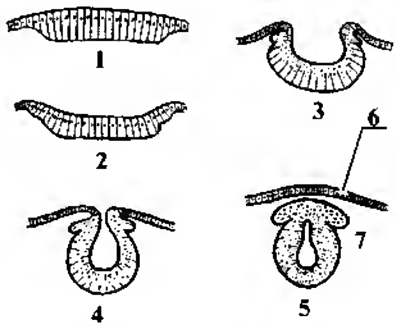

Fig. 2. Development of the nervous system (scheme). 1 – neural plate, 2, 3 – neural groove, 4, 5 – neural tube, 6 – epidermis, 7 – neural crests.

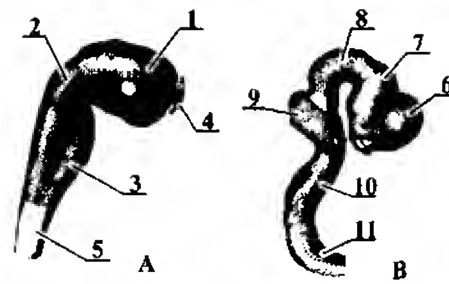

Fig. 3. Development of human brain (scheme) A – stage of three cerebral vesicles, B – stage of five cerebral vesicles. 1 – prosencephalon; 2, 8 – mesencephalon; 3 – rhombencephalon; 4 – vesicula optica; 5, 11 – medulla spinalis; 6 – telencephalon; 7 – diencephalon; 9 – metencephalon; 10 – myelencephalon.

dilations called primary vesicles because of thin walls and large cavities filled with fluid.

Three primary vesicles

The biggest anterior dilation matches the frontal region of embryo's head (fig. 3). This vesicle is called the *forebrain* or *prosencephalon* (Lat. Id). Smaller middle vesicle, *midbrain* or *mesencephalon* (Lat. Id.) is delimited from the rest of compartments by minor narrowed areas. The caudal vesicle is called the *hindbrain* or *rhombencephalon* (Lat. Id.); it is continuous with the spinal cord.

Formation of five secondary cerebral vesicles

The stage of three vesicles is transient, and by the end of the fourth week, the neural tube undergoes further subdivision with formation of five cerebral vesicles. These vesicles give rise to respective compartments of the brain.

Secondary subdivisions affect only cranial and caudal vesicles while the middle one remains unchanged. Thus, in the beginning of the second month of development, the brain appears to comprise five secondary vesicles as follows:

1) The *telencephalon* (Lat. Id.);

2) The *diencephalon* (Lat. Id.); both telencephalon and diencephalon originate from the prosencephalon;

3) The *midbrain* or *mesencepha-lon* (Lat. Id.) that originates from the middle primary vesicle;

4) The *metencephalon* (Lat. Id.);

5) The *myelencephalon* (Lat. Id.); the last two compartments originate from the rhombencephalon, which is the caudal primary vesicle.

Formation of neural tube flexures

Apart from secondary vesicles, the neural tube develops several flexures that result from area-dependent growth intensity. The flexures are directed both ventrally and dorsally. The most remarkable of the dorsal flexures is the parietal flexure located in the area of middle vesicle. Another dorsal flexure is visible on the border between the fifth vesicle and the spinal cord. Somewhat later, another remarkable flexure appears in the area of pons. This so-called pontine flexure is directed ventrally.

Differentiation of the brain

Hemispheres primordia become evident in the telencephalon area at the sixth week of development. They grow quite rapidly and eventually almost cover other compartments. Small prominence on ventral surface of each hemisphere gives rise to rhinencephalon primordium.

Within the hemispheres, the nuclei of corpus striatum grow and protrude into the lateral ventricles. Cerebral cortex develops on the surface of hemispheres.

Sulci and gyri become distinguishable in the beginning of the second half of embryo development. The lateral (Sylvian) sulcus is the first to appear on hemisphere surface, next comes the central (Rolando's) sulcus followed by the calcarine sulcus and other. During last months of development, the surface of hemispheres acquires characteristic furrowed look. Cavities within the telencephalon transform into the lateral ventricles.

In the diencephalon, the most intensive growth is observed on the lateral side, where the sensory nuclei of thalamus reside. Here also the epithalamic region with featured pineal body develops. The ventral portion of the diencephalon gives rise to subthalamic region and posterior lobe of pituitary. The cavity of diencephalon transforms into unpaired third ventricle. Diencephalon also gives rise to optic vesicles protruding ventrally; they in turn differentiate into retina, optic nerves and optic tracts.

The mesencephalon gives rise to tectal plate and cerebral peduncles and its cavity transforms into the aqueduct (Sylvian aqueduct).

Dorsal portion of metencephalon gives rise to cerebellum while the

ventral portion – to the pons. The fifth vesicle transforms into the medulla oblongata. The metencephalon and the medulla oblongata share the cavity of rhombencephalon that transforms into the fourth ventricle. Its floor is represented with the rhomboid fossa called so for characteristic shape.

Development of the spinal cord

As the neural tube grows, its walls become thicker and the cavity transforms into the central canal. The primordium of spinal cord becomes separated into ventral and dorsal portions by the *longitudinal sulcus* (**sulcus limitans**) that runs along the internal surface of the central canal on each side.

Later on, the wider ventral portion gives rise to ventral columns of grey matter. Here, the neuroblasts differentiate into big motor neurons; their axons grow and quit the spinal cord to form the ventral (anterior) roots.

Some cells migrate from the ventral columns to lateral portions and form the lateral columns that comprise the autonomic nuclei.

The dorsal portion gives rise to the dorsal columns of grey matter with featured sensory nuclei.

The central processes of pseudounipolar neurons located within the spinal ganglia primordia grow in direction of the ventral columns and form the ventral (posterior) roots of spinal cord.

At the end of third month, the grey matter appears fully differentiated while the white matter is not well distinguishable in this period.

Further, the processes of neurons exhibit rapid growth and acquire myelin sheath that results in formation of white matter that encloses the gray matter. Myelinization of the nerve fibers begins from the second half of embryo development and continues after birth.

Spinal cord growth lag

The spinal cord fully matches the vertebral canal up to the third month of development. Later on, spinal cord lags behind body growth and the caudal part of spinal cord even undergoes involution and eventually transforms into *filum terminale* (Lat. Id.).

Further, the vertebral column ever leads over the spinal cord and as far as the cranial portion of it attaches to the brain growth lag is observed in caudal portion. Shortening of the caudal portion resembles ascending (sometimes called 'spinal cord ascent'). In newborn, the caudal end of spinal cord reaches L3 and in adult individuals, it is found between L1 and L2.

The roots and spinal ganglia develop at first months of embryo life when the spinal cord matches the vertebral canal so the roots leave the spinal cord at right angle and run to respective intervertebral foramina. As the result of 'spinal cord ascent', the roots take skewed route and some even run vertically down within the vertebral canal before reaching the respective outlets. Thus, the roots of lower ten segments of spinal cord (lower four lumbar, five sacral and coccygeal segment) form the *cauda equina* (Lat. Id.) that comprises the *filum terminale* (Lat. Id.).

Practice questions

1. Give definition of network-type nervous system.
2. Discuss the structure of ganglion-type nervous system.
3. Describe formation of tubular nervous system in chordates.
4. Discuss brain phylogeny basing on CNS features in:
a) fish;
b) amphibians;
c) reptiles
d) mammals
5. Discuss the essence of brain compartments hierarchy.
6. Discuss features of human brain.
7. Do intellectual abilities depend on brain weight?
8. Describe development of CNS in humans.
9. What primary vesicles develop on the cranial end of neural tube&?
10. Name the secondary vesicles.
11. Describe the flexures of neural tube.
12. Describe development of spinal cord
13. What processes lead to formation of cauda equina?

THE SPINAL CORD, MEDULLA SPINALIS

Terminology

Synonym '**myelos**' (Greek) gives rise to 'myelin', poliomyelitis and other clinical terms.

EXTERNAL FEATURES

The spinal cord appears as whitish flattened strand 40-45 cm long and 1 cm thick. It occupies the vertebral canal and expands from the foramen magnum to upper border of L2 (Fig. 4). Its caudal end terminates with the *medullary cone*, **conus medullaris** with *filum terminale* (Lat. Id.) that arises from the end of it.

The upper portion of the filum terminale consists of nervous tissue and is a rudimentary distal portion of the spinal cord. This 15 cm long portion is called the *spinal part of filum terminale*, **pars spinalis fili terminalis**; it runs downwards surrounded by the roots of lumbar and sacral nerves. Below L2, the filum comprises only spinal meninges. This portion is 8 cm long; it attaches to periosteum of the second coccygeal vertebra. In this portion, the *dural part*, **pars duralis** and *pial part*, **pars pialis** are distinguishable.

Clinical applications

As far as the spinal cord ends on the level of L2, this appears to have great clinical significance because space between L3 and L4 can be used for safe puncturing of vertebral canal with variety of purposes.

Enlargements of spinal cord

In spinal cord, there are two enlargements distinguishable:

- the *cervical enlargement*, **intumescentia cervicalis** that appeared as the result of accumulation of the neurons and the nerve fibers that are responsible for supply of the upper limbs; it occupies the area from the fourth cervical to the first thoracic segment;
- the *lumbosacral enlargement*, **intumescentia lumbosacralis** that houses the mass of neurons and nerve fibers that supply the lower limbs; it occupies the area from the second lumbar down to third sacral segment.

The animals that lack limbs (snakes) lack enlargements as well.

Fissures and sulci

The surface of the spinal cord features sulci and fissures as follows:

- the *anterior median fissure*, **fissura mediana anterior**, deeper one, it runs along the anterior surface

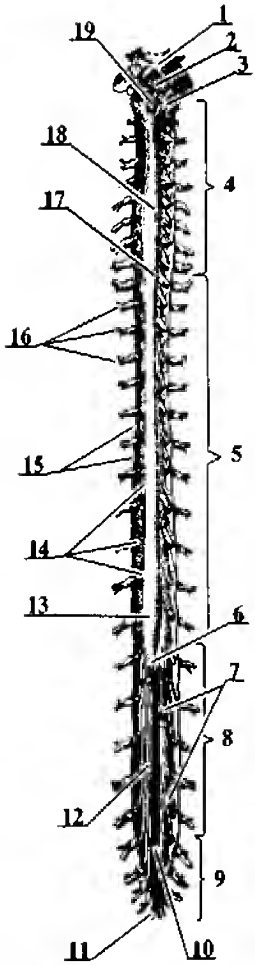

Fig. 4. The spinal cord with the roots and the spinal nerves (posterior view). 1 – tectum mesencephali; 2 – fossa rhomboidea; 3 – pedunculus cerebellaris inferior; 4 – nn. spinales cervicales (C1-C8); 5 – nn. spinales thoracici (Th1-Th12); 6 – conus medullaris; 7 – cauda equina; 8 – nn. spinales lumbales (L1-L5); 9 – nn. spinales sacrales (S1-S5); 10 – filum terminale; 11 – n. spinalis coccygeus; 12 – filum terminale, pars spinalis; 13 – intumescentia lumbosacralis; 14 – lig. denticulatum; 15 – dura mater spinalis; 16 – ganglia spinale; 17 – sulcus medianus posterior; 18 – intumescentia cervicalis; 19 – obex.

from beginning down to the terminal portion of the spinal cord; it separates the spinal cord into left and right halves;

- the *posterior median sulcus*, **sulcus medianus posterior** not that deep, it runs in the same fashion as previous; from the sulcus the *posterior median septum*, **septum medianum posterior** that physically separates left and right halves of the spinal cord arises;
- the *anterolateral sulcus*, **sulcus anterolateralis** paired, it passes the anterior roots;
- the *posterolateral sulcus*, **sulcus posterolateralis** also paired, it passes the posterior roots.

The funiculi

The sulci that run along the white matter delimit several regions called the funiculi:

- the *anterior (ventral) funiculus*, **funiculus anterior** delimited by the anterior median fissure and the anterolateral sulcus;
- the *lateral funiculus*, **funiculus lateralis** delimited by the anterolateral and posterolateral sulci;
- the *posterior (dorsal) funiculus*, **funiculus posterior** delimited by the posterolateral and posterior median sulci.

The roots of spinal nerves

The roots of spinal nerves are distinguishable along the whole length of spinal cord. They form two vertical rows. Each root consists of the *rootlets*, **fila radicularia** (fig. 5). There are

two types of the roots – the anterior and the posterior:

- the *anterior (motor) root*, **radix anterior (motoria)**, it arises from the anterolateral sulcus and contains a set of axons of motor neurons located within the anterior columns; the anterior roots number 31 pair;
- the *posterior (sensory) root*, **radix posterior (sensoria)**, it is a set of central processes of sensory pseudounipolar neurons located within the spinal ganglia; the posterior roots also number 31 pair.

The spinal ganglion, ganglion spinale

The spinal ganglion belongs to posterior root and is situated inside the intervertebral foramen around the junction of the roots. The ganglion contains the sensory (receptor) pseudounipolar neurons. Each of the cells possesses short process that

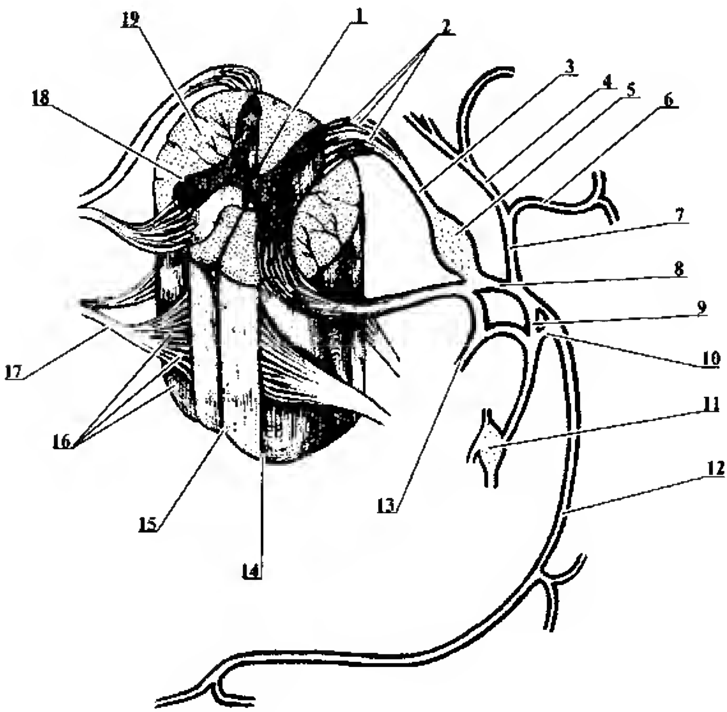

Fig. 5. The spinal segment and spinal nerve (scheme). 1 – sulcus medianus posterior; 2 – fila radicularia radicis posterioris; 3 – radix posterior; 4 – r. medialis r. posterioris n. spinalis; 5 – ganglion spinale; 6 – r. lateralis r. posterioris n. spinalis; 7 – r. posterior n. spinalis; 8 – n. spinalis; 9 – r. communicans albus; 10 – r. communicans griseus; 11 – ganglion trunci sympathici; 12 – r. anterior n. spinalis; 13 – r. meningeus n. spinalis; 14 – sulcus lateralis anterior; 15 – fissura mediana anterior; 16 – fila radicularia radicis anterioris; 17 – radix anterior; 18 – substantia grisea; 19 – substantia alba.

separates into peripheral process that runs within the spinal nerve and ends with receptor and central process that runs within the posterior root and enters the spinal cord. Totally, there is 31 pair of spinal nerves. In the area of intervertebral foramen, the anterior roots join the peripheral processes of sensory pseudounipolar cells to form the *spinal nerve*, **nervus spinalis.**

The cauda equina

As mentioned previously, the spinal cord is shorter than the vertebral canal. In view of the fact that the roots run to the respective intervertebral foramina only in cervical region they run horizontally; the lower the root is the more slanted route it takes. Finally, below the medullary cone the roots from lumbar, sacral and coccygeal segments descend almost vertically and join the filum terminale to form the *cauda equina* (Lat. Id.).

The segments of spinal cord

As the oldest compartment of the CNS, the spinal cord retains its segmentation. The segment is a portion of the spinal cord that gives rise to one pair of spinal nerves. Total number of spinal segments is 31 (fig. 6):

- the *cervical segments*, **segmenta cervicalia** [C1-C8]; upper four segments are related to C1-C4 and the lower four are related to C4-C7;
- the *thoracic segments*, **segmenta thoracica** [Th1-Th12]; they are related to the area between C7 and Th9. They are arranged so that upper four segments are related to C7-Th3, middle four are related to Th3-Th6 and lower four – to Th6-Th9;
- the *lumbar segments*, **segmenta lumbalia** [L1-L5], which are related to Th10-Th11 vertebrae;
- the *sacral segments*, **segmenta sacralia** [S1-S5] related to Th12-L1;
- the *coccygeal segment*, **segmentum coccygeum** [Co1] related to lower border of L1.

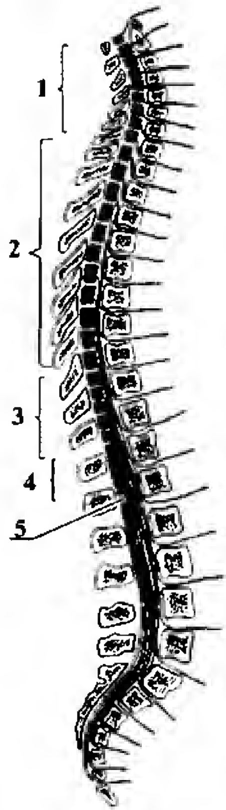

Fig. 6. Skeletal relations of the spinal cord. 1 – segmenta cervicalia (C_I-C_{VIII}); 2 – segmenta thoracica (Th_I-Th_{XII}); 3 – segmenta lumbalia (L_I-L_V); 4 – segmenta sacralia (S_I-S_V); 5 – segmentum coccygeum (Co_I).

Each segment is responsible for the respective skin area (dermatome) supplied by the posterior root of the segment given. Therefore, it is not difficult to diagnose segmental innervation disorders in typical cases. Each anterior (motor) root in turn supplies the group of muscles that arises from the respective myotome.

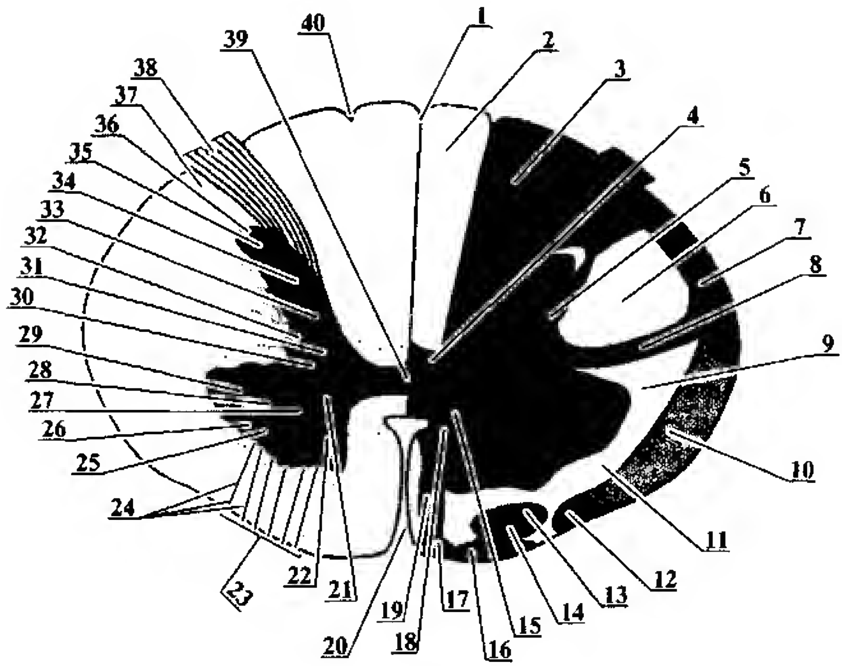

Fig. 7. The white and the grey matters of spinal cord. 1 — sulcus medianus posterior; 2 — fasciculus gracilis; 3 — fasciculus cuneatus; 4 — fasciculus proprius posterior; 5 — fasciculus proprius lateralis; 6 — tractus corticospinalis lateralis; 7 — tractus spinocerebellaris posterior; 8 — tractus rubrospinalis; 9 — tractus spinotectalis; 10 — tractus spinocerebellaris anterior; 11 — tractus spinothalamicus lateralis; 12 — tractus olivospinalis; 13 — tractus reticulospinalis anterior; 14 — tractus spinothalamicus anterior; 15 — fasciculus proprius anterior; 16 — tractus vestibulospinalis; 17 — tractus tectospinalis; 18 — fasciculus longitudinalis medialis; 19 — tractus corticospinalis anterior; 20 — fissura mediana anterior; 21 — nucl. posteromedialis; 22 — nucl. anteromedialis; 23 — radix anterior; 24 — fila radicularia anteriores; 25 — nucl. anterolateralis; 26 — nucl. nervi accessorii; 27 — nucl. nervi phrenici; 28 — nucl. centralis; 29 — nucl. posterolateralis; 30 — nucl. parasympathicus sacralis; 31 — nucleus intermediomedialis; 32 — nucleus intermediolateralis; 33 — nucl. thoracicus posterior; 34 — nucl. proprius; 35 — substantia gelatinosa; 36 — zona spongiosa; 37 — zona terminalis; 38 — radix posterior; 39 — canalis centralis; 40 — sulcus posterolateralis.

INTERNAL FEATURES OF SPINAL CORD

The spinal cord consists of inner gray matter and outer white matter. Within the spinal cord, there is a narrow *central canal*, **canalis centralis** that communicates with the fourth ventricle superiorly and terminates with slightly dilated cavity inferiorly[1].

THE GREY MATTER, SUBSTANTIA GRISEA

Along the whole length of the spinal cord on both sides, the grey matter appears as the *grey columns*, **columnae griseae**. They are joined by grey commissure separated by the central canal into *anterior grey commissure*, **commissura grisea anterior** and *posterior grey commissure*, **commissura grisea posterior**. Each column features anterior expanded portion called the *anterior (ventral) column*, **columna anterior (ventralis)** and posterior narrowed portion called the *posterior (dorsal) column*, **columnna posterior (dorsalis)**. Between the anterior and posterior columns, the gray matter also forms the *intermediate column*, **columna intermedia** present in the area between C8 and L2.

On cross-section of the spinal cord, the columns are represented with anterior, lateral and posterior horns and its shape resembles butterfly or letter 'H' (fig. 7).

The *anterior horn*, **cornu anterius** comprises the motor neurons that form five nuclei (two medial, one central and two lateral ones) and they are the *anterolateral nucleus*, the *posterolateral nucleus*, the *central nucleus*, the *anteromedial nucleus*, the *posteromedial nucleus* (**nucll. anterolaterais, posterolateralis, centralis, anteromedialis et posteromedialis**). Apart from this, the cervical segments C1 through C6 contain the *nucleus of accessory nerve*, **nucleus nervi accessorii** and the segments C4 through C7 contain the *nucleus of phrenic nerve*, **nucleus nervi phrenici**. The motor nuclei consist of large multipolar neurons; their axons quit the spinal cord and form the anterior roots. Apart from the big motor neurons marked as α- and β-neurons, the anterior columns contain γ-neurons that constitute about one third of all motor cells. The axons of α- and β-neurons terminate within the muscles with synaptic knobs while the axons of γ-neurons are connected to the muscle receptors (proprioceptors) called muscle spindles.

Clinical applications

The neurons of anterior columns are selectively susceptible to poliomyelitis virus, which causes peripheral paralysis of skeletal muscles supplied by respective segment.

[1] - this dilated lower portion of the central canal is called the *terminal ventricle*, **ventriculus terminalis**.

The *posterior horn*, **cornu posterius** comprises small multipolar interneurons that accept several sensory fibers from the posterior roots. In the posterior horn, several areas are distinguishable as follows:

- the *base*, **basis** that neighbors intermediate column and the grey commissure. It contains interoceptive centers;
- the *neck*, **cervix** is the narrowed portion next to base. Its portion that borders on the base contains the *nucleus proprius* (Lat. Id.), which is the spinal center of exteroceptive sensitivity;
- the *head*, **caput** appears as somewhat expanded outer portion of the posterior horn. On its way in direction to the posterior root, it gradually narrows and terminates with the *apex* (Lat. Id.) which consists of *gelatinous substance*, **substantia gelatinosa** and *spongy zone*, **zona spongiosa** formed of small neurons. The head shares the nucleus proprius with the neck; gelatinous substance and nucleus proprius form joint spinal center of exteroceptive sensitivity.

The *lateral horn*, **cornu laterale** is present in the area between C8 and L2. Between anterior and posterior horns, there is the central intermediate substance, which continues medially into narrower grey commissure that connects left and right halves of the grey matter.

The area from C8 through L2 contains aggregated sympathetic neurons that form the *intermediolateral nucleus*, **nucleus intermediolateralis**. Axons of those cells join the anterior roots and run to the respective sympathetic ganglia.

In the segments S2 through S4 the lateral horns are not evident and the intermediate substance contains the *sacral parasympathetic nuclei*, **nuclei parasympathici sacrales**. Axons of the cells of these nuclei join the anterior roots and run to pelvic parasympathetic ganglia.

Thus, the intermediate zone contains the spinal autonomic centers that supply the viscera and the blood vessels.

Medially to the intermediolateral nucleus the *intermediomedial nucleus*, **nucleus intermediomedialis** is situated; it is a spinal center of proprioceptive sensitivity.

It should be noted, that the nuclei of the grey matter are mapped as ten spinal laminae. Generally, topography of spinal laminae is identical to nuclei topography except for minor mismatches (fig. 8):

- the *spinal lamina I*, **lamina spinalis I** appears as thin marginal layer related to dorsal and partially lateral surface of the posterior horn; it matches the *marginal nucleus*, **nucleus marginalis**. Neurons of this lamina respond to pain and temperature stimuli and carry the fibers to the *lateral spinothalamic tract*, **tractus spinothalamicus lateralis**;
- the *spinal lamina II*, **lamina spinlis II** resides ventrally to previous lamina and runs along the whole

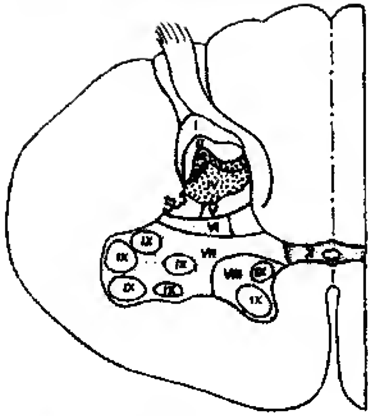

Fig. 8. Topography of the spinal laminae.

length of spinal cord. It matches the *gelatinous substance,* **substantia gelatinosa**. Internal zone of the lamina accepts pain and temperature related fibers and the internal zone accepts tactile sensitivity fibers;

- the *spinal laminae III, IV and V,* **laminae spinales III, IV et V** run all along the spinal cord. They are the components of the *nucleus proprius* (Lat. Id.). The nucleus give rise to *anterior spinothalamic tract,* **tractus spinothalamicus anterior** and its neurons respond to tactile stimuli;
- the *spinal lamina VI,* **lamina spinalis VI** is present only within the enlargements of spinal cord. Their neurons respond to proprioceptive impulses from muscles;
- the *spinal lamina VII,* **lamina spinalis VII** resides between the anterior and posterior horns. Within the enlargements, the lamina even enters the anterior horns. At the level of Th1 through L3 it joins the posterior horns;
- the *spinal lamina VIII,* **lamina spinalis VIII** contains several nuclei. The *posterior thoracic nucleus,* **nucleus thoracicus posterior** comprises the neurons located within the medial portion of the lamina at the level of C8 through L2. This nucleus gives rise to *posterior spinocerebellar tract,* **tractus spinocerebellaris posterior.** The *intermediolateral nucleus,* **nucleus intermediolateralis** resides within the lateral column at the level of Th1 through L2. Neurons of this nucleus give rise to preganglionic sympathetic fibers that quit the spinal cord within the anterior roots and form the white ramus communicans of the spinal nerve. The *intermediomedial nucleus,* **nucleus intermediomedialis** located at the level of Th1 through L3 is responsible for visceral sensitivity. The *sacral parasympathetic nuclei,*

nuclei parasympathici sacrales located at the level of S2 through S4 contain the bodies of preganglionic neurons that participate in supplying of the pelvic viscera; the *spinal lamina VIII* within the enlargements reaches the middle portion of the anterior horns. In the rest of areas, it resides within the base of the anterior horns ventrally to the spinal lamina VII;

- the *spinal lamina IX*, **lamina spinalis IX** fully matches the area of motor neurons of the anterior horns;
- the *spinal lamina X*, **lamina spinalis X** constitutes an area of grey matter adjacent to the central canal.

THE WHITE MATTER, SUBSTANTIA ALBA

The white matter comprises the *fasciculi* (Lat. Id.) of nerve fibers that form various *tracts* (**tractus**). It enfolds the gray matter and is divided into anterior, lateral and posterior funiculi.

The tracts of the spinal cord can be subdivided as follows:

1) the *fasciculi proprii* (Lat. Id) that associate the segments of spinal cord. They begin from the interneurons of the gray matter and run close to it because they are phylogenetically older than the rest. Together with nearby grey matter the proper fasciculi form the segmental apparatus of spinal cord;

2) the two-way association apparatus of the brain and the spinal cord and comprises the bundles that run from the spinal centers and the spinal ganglia to the brain (sensory or afferent tracts) and the bundles that run in opposite direction (motor or descending tracts).

The *anterior funiculus*, **funiculus anterior** contains the fasciculi as follows:

- the *anterior fasciculus proprius*, **fasciculus proprius anterior;**
- the *anterior corticospinal tract*, **tractus corticospinalis anterior** that runs from the cerebral cortex to the motor neurons of the anterior columns;
- the *lateral* and *medial vestibulospinal tracts*, **tractus vestibulospinalis latralis et medialis** that run from the vestibular nuclei of the brainstem to the motor neurons of anterior columns;
- the *anterior spinothalamic tract*, **tractus spinothalamicus anterior** that arises from the cells of the gelatinous substance of the apex of posterior horn and ascends to reach the thalamus; it transmits the impulses of tactile sensitivity;
- the *tectospinal tract*, **tractus tectospinalis** that arises from the *tectum of midbrain*, **(tectum mesencephali)** namely from the proper nuclei of superior and inferior colliculi and reaches the motor neurons of anterior columns;
- the *reticulospinal fibers*, **fibrae reticulospinales** that arises from the reticular formation of brainstem to autonomic neurons of the lateral columns and the motor neurons of anterior columns.

The *lateral funiculus*, **funiculus lateralis** contains the following fasciculi:

- the *lateral fasciculus proprius*, **fasciculus proprius lateralis**;
- the *lateral corticospinal tract*, **tractus corticospinalis lateralis** that arises from the cerebral cortex to the motor neurons of the anterior columns. This tract is the largest in the area, it occupies the central portion of the funiculus;
- the *rubrospinal tract*, **tractus rubrospinalis** that arises from the *red nucleus*, **nucleus ruber** of the midbrain and descends to motor neurons of anterior horns; it neighbors previous tract;
- the *olivospinal fibers*, **fibrae olivospinales** that arise from the inferior olive of brainstem to the motor neurons of the anterior columns;
- the *lateral spinothalamic tract*, **tractus spinothalamicus lateralis**. It arises from the cells located within the head of posterior horn and ascends to the thalamus; it transmits the impulses of pain and temperature sensitivity;
- the *anterior (ventral) spinocerebellar tract*, **tractus spinocerbellaris anterior (ventralis)** (Gowers' tract) that arises from the cells of intermediomedial nucleus and ascends to the cerebellum; it occupies the ventral peripheral portion of funiculus. The tract transmits impulses of proprioceptive sensitivity;
- the *posterior (dorsal) spinocerebellar tract*, **tractus spinocerbellaris posterior (dorsalis)** (Flechsig's tract) that arises from the thoracic nucleus of posterior horn and runs along the ventral peripheral part of the funiculus to the cerebellum; the tract also transmits impulses of proprioceptive sensitivity.

The *posterior funiculus*, **funiculus posterior** contains the following fasciculi:

- the *posterior fasciculus proprius*, **fasciculus proprius posterior;**
- the *gracile fasciculus*, **fasciculus gracilis** (Goll's tract). It resides medially and is represented with the central processes of sensory pseudounipolar cells. It ascends to the medulla oblongata and transmits the proprioceptive impulses from lower limbs and lower portion of trunk;
- the *cuneate fasciculus*, **fasciculus cuneatus** (Burdach's tract) that resides laterally from the previous. It is also represented with the central processes of sensory pseudounipolar neurons located within the spinal ganglia; it ascends to the medulla oblongata as well and functions identically to the previous but collects the impulses from the upper limbs and upper portion of trunk. Both bundles are evident at the level of Th4 and up; below this level, only gracile fasciculus is present.

The spinal reflex arc

All activities of CNS are based on reflexes both conditioned and unconditioned. Reflex is a response of an or-

ganism to external or internal stimulus that involves CNS.

In evolution process, the spinal cord is the first to appear as a solid structure and simple reflex reactions to exterior and interior stimuli synapse within it. Reflexes employ the reflex arcs, the simplest of which consist of two neurons: afferent (sensory) and efferent (motor). Such reflex arc is called monosynaptic. Typically, the reflex arc comprises three neurons:

1) the sensory neurons located within the spinal ganglia. The peripheral processes of sensory pseudounipolar neurons project to the receptors of the trunk and extremities (the receptors are located within skin, mucous membranes and tendons) that accept stimuli and generate nerve impulses. The impulses eventually reach the posterior horn of spinal cord via the posterior root and proceed to the interneurons;

2) the interneurons of simple reflex arc are located within older portions of spinal cord namely the marginal nucleus, the gelatinous substance and the *disseminated cells* **(cellulae disseminatae)** located between the nuclei of posterior horns and intermediate zone. They are small multipolar cells; their axons take two distinguishable routes: some project directly to the motor nuclei of anterior grey columns and some branch off to give ascending and descending branches that synapse with the motor nuclei of upper and lower segments. These branches run 5-6 segments up and 5-6 segments down and form the *fasciculi proprii* (Lat. Id.) adherent to grey substance. Thus, even small number of receptors stimulated involves nearly a half of spinal segments and related muscles;

3) the motor neurons of the anterior grey columns; their axons quit the spinal cord through the anterior root and run within the spinal nerve to reach the respective muscles and set them to motion.

Thus, the grey matter with related roots and fasciculi proprii form the proper or segmental apparatus responsible for unconditioned reflexes.

Reflex circuit and loopback principle

In recent years, the concept of reflex arc underwent major revision due to new data obtained.

The nervous system monitors muscular contractions by means of proprioceptors associated with CNS via sensory fibers. In muscles, the proprioceptors are represented with muscle spindles. Some spindles respond to muscle stretch and some – to contraction. The impulses run to the spinal cord via the sensory pseudounipolar neurons. In the spinal cord, the sensory-motor associations are mediated by interneurons.

The nervous system thus continuously receives data on muscle tonus status. The system functions as a circuit based on negative loopback principle. The motor neurons generate correction impulses for muscle contractions increasing thus movements' precision.

It was found (Leksell, 1945) that except for the α-neurons responsible for muscles contractions the anterior grey columns feature small γ-neurons, which supply the intrafusal fibers of muscle spindles. These neurons regulate sensitivity of stretch receptors and optimize their work.

The loopback principle is universal for all activities of CNS (P. K. Anokhin).

Practice questions

1. Discuss general features of the spinal cord: topography, upper and lower boundaries and external features.
2. Discuss the posterior roots of spinal cord: origin, topography and functional significance.
3. Discuss the anterior roots of spinal cord: origin, topography and functional significance.
4. Discuss formation of spinal nerve.
5. Describe topography, structure and functions of the spinal ganglion.
6. Give definition of the cauda equina and describe its structure.
7. Give definition of the spinal segment.
8. Describe cross-section of spinal cord.
9. Describe the posterior horns of grey matter: the neurons, the nuclei and their functional features.
10. Describe the lateral horns of grey matter: the neurons, the nuclei and their functional features.
11. Describe the anterior horns of grey matter: the neurons, the nuclei and their functional features.
12. Describe the white matter of spinal cord: general classification, short fibers and their formation, topography and functions.
13. Describe long fibers of the white matter: classification, formation and functions.
14. Describe the anterior funiculi of spinal cord: boundaries and related tracts.
15. Describe the lateral funiculi of spinal cord.
16. Describe the posterior funiculi of spinal cord.
17. What is the morphological base of reflexes? Describe the simple reflex arc.
18. Give definition of loopback principle.

THE BRAIN, ENCEPHALON

The term **'encephalon'** originates from two Greek words: **'en'** – 'within', and **'kephale'** – 'head'.

The brain with related meninges resides within the neurocranium. Its convex superolateral surface adjoins the bones of calvaria and the inferior surface features complex shape and matches the cranial fossae of internal cranial base.

In adult individuals, weight of brain ranges from 1100 to 2000 grams; with aging, beginning from 60 years of age, weight and volume of brain reduce.

The brain consists of three large principal parts:

- the *cerebral hemispheres*, **hemispheriae cerebri**
- the *cerebellum* (Lat. Id.)
- the *brainstem*, **truncus encephali**.

The brainstem is the oldest part of brain (**palencephalon**). It is a continuation of the spinal cord and it forms segmental apparatus of brain. It gives rise to cranial nerves well resembling the spinal nerves.

The newest part of the brain (**neoencephalon**) is represented with cerebral hemispheres and related *cerebral cortex*, **pallium** that covers underlying compartments.

The hemispheres are separated with deep *longitudinal cerebral fissure*, **fissura longitudinalis cerebri**. Posteriorly it joins the *transverse cerebral fissure*, **fissura transversa cerebri** that separates the cerebral hemispheres from the cerebellum.

Surface of hemispheres features numerous *cerebral sulci*, **sulci cerebri**. Deeper *interlobar sulci*, **sulci interlobares** delimit the *cerebral lobes*, **lobi cerebri**. Smaller and shallower sulci delimit the *cerebral gyri*, **gyri cerebri** on respective lobes.

Overview of the inferior surface of brain

The inferior surface is formed of cerebral hemispheres (larger anterior portion), the cerebellum (smaller posterior portion) and the brainstem (its ventral surface) that runs along the midline. The anterior portion of surface is separated by well visible *longitudinal cerebral fissure*, **fissura longitudinalis cerebri** (Fig. 9). Laterally to it, there are two small swellings adherent to the frontal lobes – the *olfactory bulbs*, **bulbi olfactorii**. Inferior surface of the bulbs contains several thin *olfactory nerves*, **nervi olfactorii** that arise from the nasal mucosa and reach the bulbs through the cribriform plate. Olfactory nerves on each side form the *olfactory nerve*, **nervus olfactorius** – the first pair of cranial nerves. Upon brain removal, the nerves tear off and are not visible on single prosection.

The olfactory bulb becomes continuous with the *olfactory tract*, **tractus olfactorius** that runs posteriorly and terminates at the *olfactory tri-*

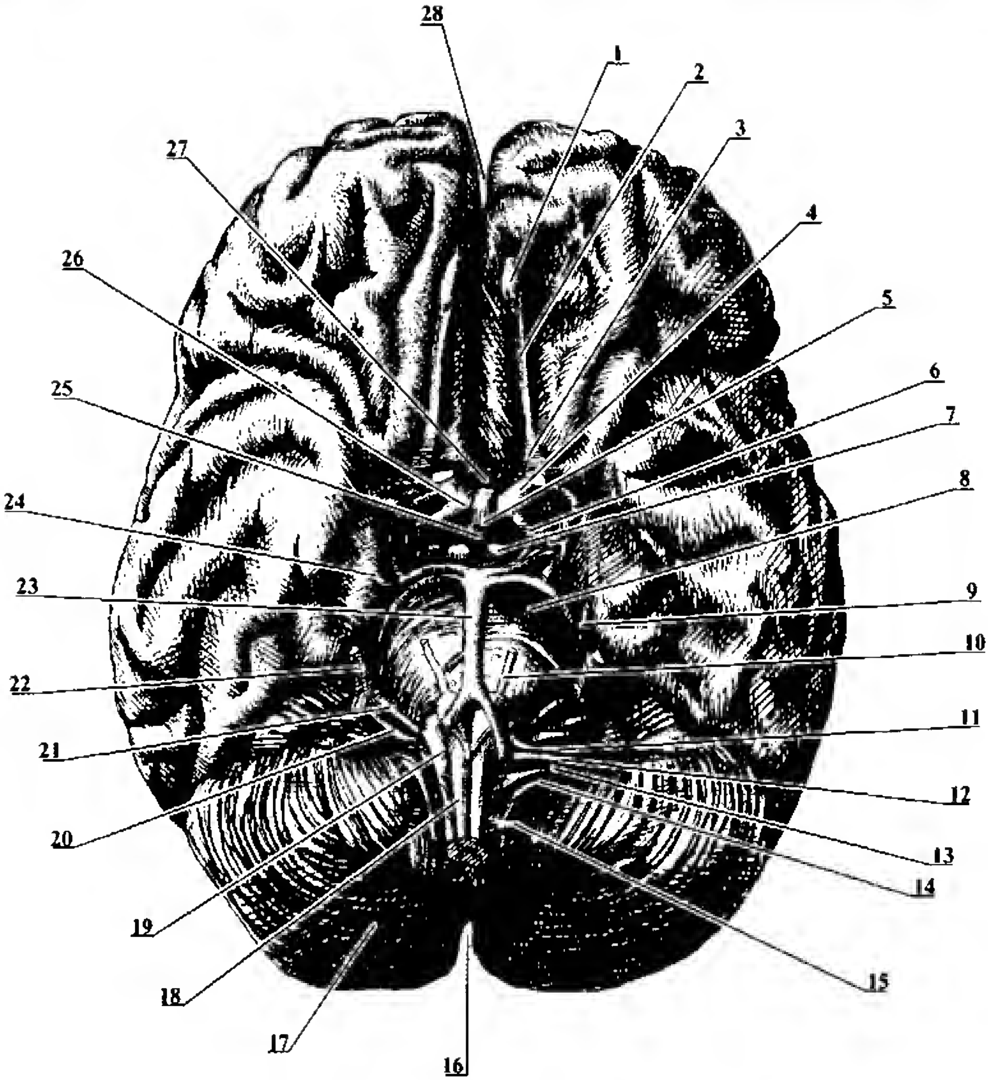

Fig. 9. The inferior surface of brain with the roots of cranial nerves. 1 – bulbus olfactorius; 2 – tractus olfactorius; 3 – trigonum olfactorium; 4 – n. opticus (II); 5 – infundibulum; 6 – tractus opticus; 7 – corpora mamillaria; 8 – pons; 9 – n. trochlearis (IV); 10 – n. abducens (VI); 11 – n. glossopharyngeus (IX); 12 – n. vagus (X); 13 – n. hypoglossus (XII); 14 – n. accessorius (XI); 15 – n. spinalis; 16, 28 – fissura longitudinalis cerebri; 17 – cerebellum; 18 – oliva; 19 – pyramis medullae oblongatae; 20 – n. vestibulocochlearis (VIII); 21 – n. facialis (VII); 22 – n. trigeminus (V); 23 – a. basillaris; 24 – n. oculomotorius (III); 25 – tuber cinereum; 26 – chiasma opticum; 27 – substatntia perforata anterior.

gone, **trigonum olfactorium**. Posterior to the latter, there are numerous openings for blood vessels — the *anterior perforated substance*, **substantia perforata anterior** that becomes visible after pia mater removal.

Area bounded by the perforated substances contains a thin plate of grey matter called the *lamina terminalis* (Lat. Id.) that closes the longitudinal fissure. Its posterior surface fuses with the *optic chiasm*, **chiasma optica**. The optic chiasm is formed of the *optic nerves*, **nervi optici** — the second pair of cranial nerves that enter the cranial cavity through the *optic canal*, **canalis opticus**. The optic chiasm gives rise to the *optic tracts*, **tractus opticus**.

Posterior surface of the optic chiasm neighbors the *tuber cinereum* (Lat. Id.) with the inferior narrowed portion called the *infundibulum* (Lat. Id.) where the *pituitary gland*, **hypophysis** attaches. The pituitary is an endocrine gland that resides within the hypophysial fossa of the sella turcica; superiorly it is covered by dura mater outgrowth called the *diaphragma sellae* (Lat. Id.). Upon brain removal, the pituitary remains within the hypophysial fossa.

Posterior to the tuber cinereum there are two rounded elevations — the *mammillary bodies*, **corpora mammillaria**. Posterior to the chiasm one can see two whitish longitudinal elevations called the *cerebral peduncles*, **pedunculi cerebri** that enclose the *interpeduncular fossa*, **fossa interpeduncularis** also bounded anteriorly by the mammillary bodies. The floor of interpeduncular fossa features numerous openings that pass the blood vessels — the *posterior perforated substance*, **substantia perforata posterior.**

On the medial surface of each peduncle, one can see the third pair of cranial nerves — the *oculomotor nerves*, **nervi oculomotorii** that arise from there.

The fourth pair of cranial nerves — the *trochlear nerves*, **nervi trochleares** — loop around the lateral surface of each peduncle. They are the thinnest nerves and unlike the rest, they arise from the dorsal surface of brainstem and traverse the superior medullary velum laterally to its frenulum.

Posteriorly, the cerebral peduncles become continuous with wide transverse elevation called the *pons* (Lat. Id.). The lateral narrowed portions of pons enter the cerebellum to form the *middle cerebellar peduncles*, **pedunculi cerebellares medii**. Anterior to the middle cerebellar peduncles, the lateral surface of the pons passes the fifth pair of cranial nerves — the *trigeminal nerves*, **nervi trigemini.**

Posterior to the pons one can see the ventral surface of the *medulla oblongata* (Lat. Id.) with the grooves continuous from the spinal cord: the *anterior median fissure*, **fissura mediana anterior** and paired *anterolateral sulci*, **sulci anterolaterales**. The grooves enclose paired eminences called the *pyramids*, **pyramides medullae oblongatae**. Laterally from the pyramids, one can see larger ovoid eminences — the *inferior olives*, **oli-**

vae. A groove between the posterior border of pons and the pyramids (the *medullopontine sulcus*) passes the sixth pair of cranial nerves – the *abducent nerves,* **nervi abducens**. The seventh pair of cranial nerves – the *facial nerves,* **nervi faciales** – arises laterally from the previous pair between the pons and the olives from the same groove. Laterally from the facial nerves one can see the eights pair of cranial nerves – the *vestibulocochlear nerves,* **nervi vestibulocochleares**.

Posterior to the olive, there is the *posterolateral sulcus,* **sulcus posterolateralis** also continuous from the spinal cord. The sulcus passes the cranial nerves as follows: the ninth pair – the *glossopharyngeal nerves,* **nervi glossopharyngei**, the tenth pair – the *vagus nerves,* **nervi vagi** and the eleventh pair – the *accessory nerves,* **nervi accessorii**. Roots of the latter nerves also arise from the upper portion of the spinal cord. The anterolateral sulcus between the pyramids and olives passes numerous roots of the *hypoglossal nerves,* **nervi hypoglossi** – the twelfth pair of cranial nerves.

Overview of the medial surface of brain

Sagittal section of the brain through the longitudinal fissure reveals the medial surface of the cerebral hemispheres that hangs over the brainstem and the cerebellum. The medial surface of hemisphere is delimited from well distinguishable large commissure – the *corpus callosum* (Lat. Id.) with deep *sulcus of corpus callosum,* **sulcus corporis callosi** (Fig. 10). The corpus callosum associates the hemispheres. The middle portion of the corpus callosum is called the *trunk,* **truncus**, the posterior thickened portion is called the *splenium* (Lat. Id.) and the anterior portion that forms sharp flexure is called the *genu* (Lat. Id.). The genu is continuous with narrowed portion called the *rostrum* (Lat. Id.) that in turn reaches the inferior surface of brain as the *lamina terminalis* (Lat. Id.) and adheres to the optic chiasm.

Below the corpus callosum, there is the whitish strand called *fornix* (Lat. Id.). Its *body,* **corpus** adheres to the corpus callosum; its anterior crus or the *column,* **columna** bends inferiorly and anteriorly to reach the mammillary body on respective side.

Between the fornix and the lamina terminalis, there is the transverse bundle of fibers called the *anterior commissure,* **commissura anterior**; being sectioned it appears as whitish oval. The commissure also associates the hemispheres.

A thin plate that expands between the genu and rostrum anteriorly and the column of fornix posteriorly is called the *lamina of septum pellucidum,* **lamina septi pellucidi**. The laminae join to form the *septum pellucidum* (Lat. Id.) that separates the anterior horns of lateral ventricles. All above listed structures originate from the *telencephalon* (Lat. Id.). Below, one can distinguish the derivatives of *diencephalon* (Lat. Id.). They are the *thalami* (Lat. Id.) that reside posterior

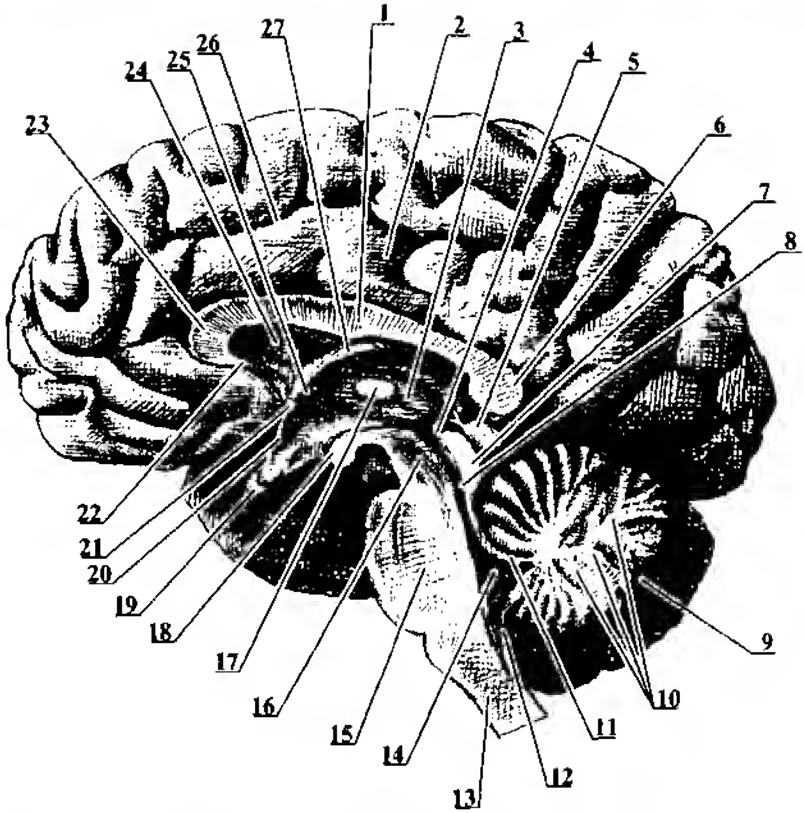

Fig. 10. The medial surface of brain (sagittal section). 1 — corpus callosum (truncus); 2 — gyrus cinguli; 3 — thalamus; 4 — comissura cerebri posterior; 5 — epiphysis (corpus pineale); 6 — splenium corporis callosi; 7 — tectum mesencephali; 8 — aqueductus mesencephali; 9 — cerebellum; 10 — arbor vitae cerebelli; 11 — vellum medullare superius; 12 — vellum medullare inferius; 13 — medulla oblongata; 14 — ventriculus IV; 15 — pons; 16 — pedunculus cerebri; 17 — adhesio interthalamica; 18 — hypophysis; 19 — n. opticus (II); 20 — lamina terminalis; 21 — comissura cerebri anterior; 22 — rostrum corporis callosi; 23 — genu corporis callosi; 24 — septum pellucidum; 25 — foramen interventriculare; 26 — sulcus cinguli; 27 — columna fornicis.

to the columns of fornix. Sagittal section reveals only medial surface of the thalamus with featured *interthalamic adhesion*, **adhesio interthalamica** that joins the thalami. The medial surfaces of the thalami form the lateral walls of the third ventricle placed vertically. A narrow passage between the column of fornix and the anterior thalamic tubercle is the *interventricular foramen*, **foramen interventriculare** that communicates the lateral ventricle with the third ventricle. Below the thalamus on can see the groove that arises from the interventricular foramen and runs posteriorly — the *hypotha-*

lamic sulcus, **sulcus hypothalamicus**. The sulcus delimits the thalamus from underlying area related to another diencephalon derivative – the *hypothalamus* (Lat. Id.). It comprises the optic chiasm, the tuber cinereum, the infundibulum, the pituitary and the mammillary bodies – structures that form the floor of fourth ventricle. Superior and posterior to the thalamus, below the splenium of corpus callosum, there is the *pineal gland*, **glandula pinealis**. Below the pineal gland, there is another transverse bundle of fibers called the *posterior commissure*, **commissura posterior seu commissura epithalamica**.

Inferior to diencephalon derivatives, one can see the structures that arise from *midbrain*, **mesencephalon**. They are the *tectal (quadrigeminal) plate*, **lamina tecti (quadrigemina)** that comprises paired superior and inferior colliculi yet two only are distinguishable on the sagittal section.

Anterior to the tectal plate, there is the cerebral peduncle separated from the tectal plate by the *aqueduct of midbrain (cerebral aqueduct)*, **aqueductus mesencephali (cerebri)**. The aqueduct is the cavity of midbrain that communicates the third ventricle with the fourth ventricle.

Below the midbrain, one can see derivatives of the metencephalon – the pons and the cerebellum and the lowest portion comprises the derivatives of myelencephalon – the medulla oblongata. The pons, the medulla oblongata and the cerebellum form the cavity of rhombencephalon – the fourth ventricle. Its floor consists of the dorsal surfaces of the pons and the medulla oblongata that constitute the rhomboid fossa. Between the inferior surface of cerebellum and the tectal plate, there is a thin plate of white matter called the *superior medullary velum*, **velum medullare superius**.

Thus, the brain comprises five compartments that develop from secondary vesicles as follows: 1) the telencephalon, 2) the diencephalon, 3) the midbrain, 4) the metencephalon and 5) the medulla oblongata that becomes continuous with the spinal cord at the level of foramen magnum.

THE RHOMBENCEPHALON, RHOMBENCEPHALON

The rhombencephalon comprises the medulla oblongata and the metencephalon (the pons and the cerebellum). The compartment contains the cavity called the fourth ventricle with the floor represented with the rhomboid fossa.

THE MEDULLA OBLONGATA, MEDULLA OBLONGATA

Terminology: related terms originate from Greek '**myelos**' – 'spinal cord' and '**encephalon**' – 'brain'. '**Medulla oblongata**' stands for 'oblong brain'. Another term – '**bulbus**' appeared because of its thickened upper portion. The primary names give rise to numerous clinical terms like bulbar paralysis etc.

The boundaries and the surfaces of the medulla oblongata

The medulla oblongata is the direct continuation of the spinal cord; the conditional boundary between them is assigned either to the first pair of spinal nerves or to the margin of foramen magnum. Superiorly, the medulla oblongata is delimited from the pons by deep *medullopontine sulcus*, **sulcus bulbopontinus** (ventrally) and the *medullary stria of fourth ventricle*, **striae medullares ventriculi quarti** that cross the rhomboid fossa (dorsally).

The medulla oblongata has ventral (anterior), dorsal (posterior) and lateral surfaces.

Ventral surface of medulla oblongata

The features of the ventral surface are like the following:

- the *anterior (ventral) median fissure*, **fissura mediana anterior**, which continues from the same fissure of the spinal cord;
- the *pyramids*, **pyramides**, paired whitish strands that run along the anterior median fissure. The pyramids contain the motor fibers that descend from the cerebral cortex to the spinal cord;
- the *decussation of pyramids*, **decussatio pyramidum** that resides below the pyramids. This is the place where most of motor fibers cross before entering the spinal cord.

The lateral surface

This surface comprises the following:

- the *inferior olive*, **oliva** – a well distinguishable paired eminence found laterally from each pyramid;
- the *anterolateral sulcus*, **sulcus anterolateralis** that runs between the pyramid and the inferior olive; the sulcus passes the roots of *hypoglossal nerve*, **nervus hypoglossus** (the twelfth pair of cranial nerves);
- the *posterolateral sulcus*, **sulcus posterolateralis** that runs posterior to the olive. This sulcus passes the roots of the following cranial nerves: the *glossopharyngeal nerves*, **nervi glossopharyngei** (the ninth pair), the *vagus nerves*, **nervi vagi** (the tenth pair) and the *accessory nerves*, **nervi accessorii** (the eleventh pair);
- the *inferior cerebellar peduncle*, **pedunculus cerebellaris inferior**, paired, it arises from the dorsal portion of lateral funiculus and accepts some fibers that arise from

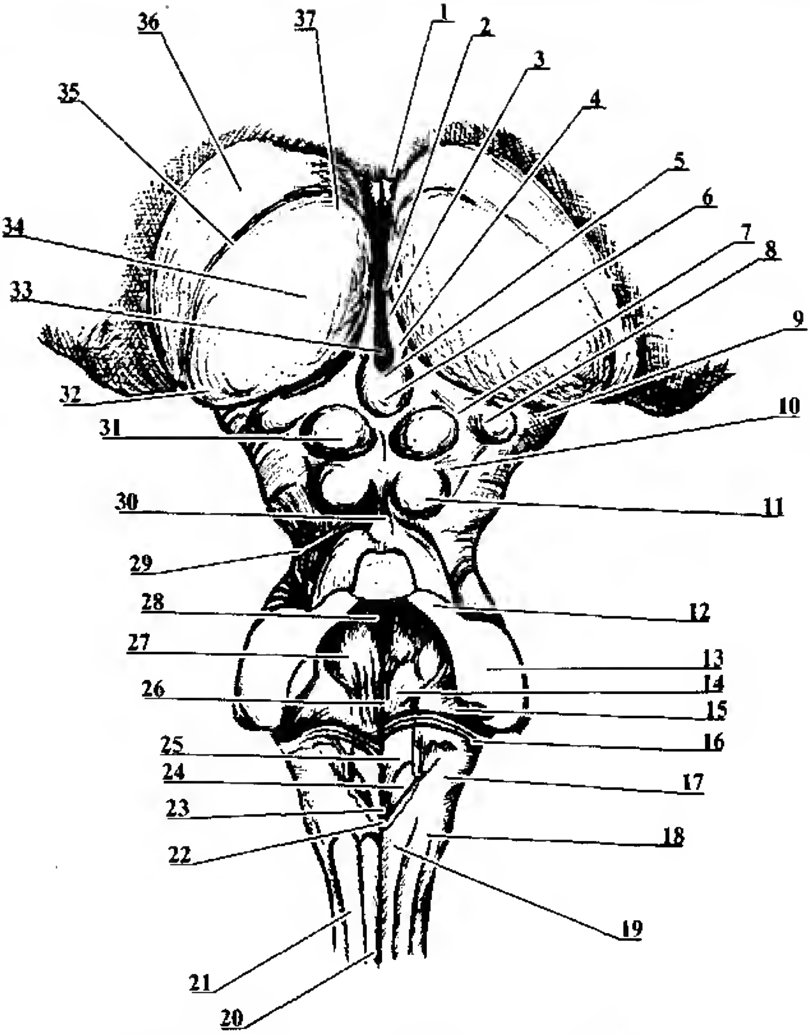

Fig. 11. The brainstem (superior view; the cerebellum is removed). 1 — columna fornicis; 2 — stria medullaris thalami; 3 — habenula; 4 — trigonum habenulare; 5 — comissura habenularum; 6 — corpus pineale; 7 — brachium colliculi superioris; 8 — corpus geniculatum mediale; 9 — corpus geniculatum laterale; 10 — brachium colliculi inferioris; 11 — colliculus inferior; 12 — pedunculus cerebellaris superior; 13 — pedunculus cerebellaris medius; 14 — colliculus facialis; 15 — area vestibularis; 16 — striae medullares ventriculi quarti; 17 — pedunculus cerebellaris inferior; 18 — tuberculum cuneatus; 19 — tuberculum gracilis; 20 — fasciculus gracilis; 21 — fasciculus cuneatus; 22 — obex; 23 — fovea inferior fossae rhomboideae; 24 — trigonum n. vagi; 25 — trigonum n. hypoglossi; 26 — sulcus medianus; 27 — locus caeruleus; 28 — fovea superior fossae rhomboideae; 29 — n. trochlearis (IV); 30 — frenulum velli medullaris superioris; 31 — colliculus superior; 32 — pulvinar thalami; 33 — ventriculus tertius; 34 — thalamus; 35 — stria terminalis; 36 — nucl. caudatus; 37 — tuberculum anterius thalami.

the cuneate and gracile nuclei. Superiorly, the peduncles part (thus forming the inferior boundaries of rhomboid fossa) and join the cerebellum.

The dorsal surface

This surface features the following (Fig. 11):

- the *posterior median sulcus*, **sulcus medianus posterior** that continues from the spinal cord;
- the *gracile fasciculus*, **fasciculus gracilis** that ascends from the spinal cord and terminates at the lower border of rhomboid fossa with the *gracile tubercle*, **tuberculum gracilis**, which contains the *gracile nucleus*, **nucleus gracilis**;
- the *cuneate fasciculus*, **fasciculus cuneatus** that ascends from the spinal cord as well and terminates with the *cuneate tubercle*, **tuberculum cuneatum** found lateral and superior to the previous. The tubercle also contains the nucleus — the *cuneate nucleus*, **nucleus cuneatus**.

The nuclei and fibers of medulla oblongata

The medulla oblongata contains important nuclei and tracts as follows:

The *cuneate* and *gracile nuclei*, **nucleus cuneatus et nucleus gracilis** found within respective tubercles. They are the nuclei of posterior funiculi that accept the cuneate and gracile fasciculi. Both fasciculi are formed of the central processes of sensory pseudounipolar cells of the spinal ganglia. The cuneate and gracile fasciculi transmit the impulses of proprioceptive and tactile sensitivity. The axons of nuclei form the medial lemniscus.

The *medial lemniscus*, **lemniscus medialis** is the bundle of neurofibers that arises from cuneate and gracile nuclei on each side and ascends to the thalamus (the *bulbothalamic tract*). Upon arising, the fibers arch in ventral direction and enter the depth of medulla oblongata to form the *decussation of medial lemniscus (sensory decussation)*, **decussatio lemnisci medialis** between the inferior olives. After crossing, the bundles loop upwards and ascend through the tegmentum of pons and the tegmentum of midbrain to reach the thalamus. On its way to the thalamus, the lemniscus accepts the spinothalamic fibers that ascend from the spinal cord (exteroceptive fibers) and the fibers from the sensory nuclei of cranial nerves (the *nucleothalamic tract*).

The *pyramidal tract*, **tractus pyramidalis** resides within the pyramids on the dorsal surface. It contains the longitudinal fibers that arise from the precentral gyrus. The pyramidal tract comprises the bulbar corticonuclear fibers and the corticospinal fibers:

- the *bulbar corticonuclear fibers*, **fibrae corticonucleares bulbi** that decussate and reach the motor nuclei of the cranial nerves;
- the *corticospinal fibers*, **fibrae corticospinales** that transit the medulla oblongata. About 80% of the fibers decussate immediately

below the pyramids and appear as *decussation of pyramids*, **decussatio pyramidum** on the ventral surface of medulla oblongata. The fibers proceed to the lateral funiculus and thus form the *lateral corticospinal tract*, **tractus corticospinalis lateralis**. The fibers that bypassed decussation (about 20%) descend to the anterior funiculus and run as the *anterior corticospinal tract*, **tractus corticospinalis anterior**. These fibers decussate within respective segments. Thus, the entire corticospinal tract appears to be fully decussated. The corticospinal fibers terminate within the anterior grey columns where they synapse with the motor neurons.

The *inferior olivary nucleus*, **nucleus olivarius inferior**, paired, it resides within the inferior olive. On the cross-sectioned medulla, it appears as dentate body open medially with the *hilum of inferior olivary nucleus*, **hilum nuclei olivaris inferioris**. The nucleus

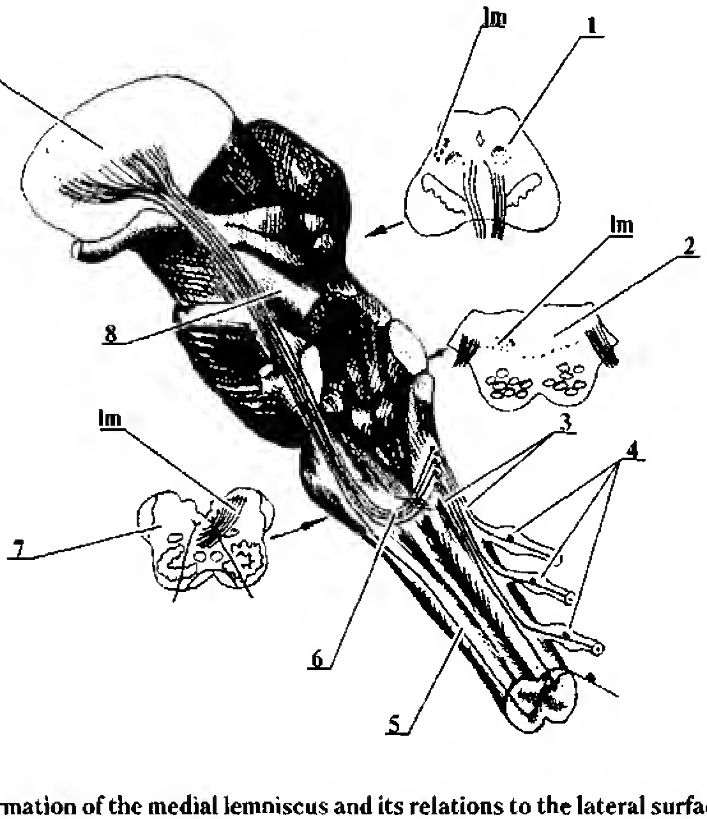

Fig. 12. Formation of the medial lemniscus and its relations to the lateral surface of brainstem. lm — lemniscus medialis; 1 — mesencephalon; 2 — pons; 3 — fasciculus gracilis et fasciculus cuneatus; 4 — ganglia spinale; 5 — tractus spinothalamicus; 6 — decussatio lemnisci medialis; 7 — medulla oblongata; 8 — pedunculus cerebri; 9 —thalamus.

communicates with the cerebellum via the *olivocerebellar tract*, **tractus olivocerebellaris** and with the spinal cord via the *olivospinal fibers*, **fibrae olivospinales**. The olivary nuclei control body equilibrium.

The *reticular formation*, **formatio reticularis** comprises small and large neurons with well-branched processes that form wide networks. It resides dorsally from the olivary nuclei and runs along the entire medulla and spinal cord.

The dorsal portion of medulla oblongata contains the nuclei of cranial nerves as follows: the hypoglossal nerve, the accessory nerve, the vagus nerve and the glossopharyngeal nerve (See 'Rhomboid fossa' section on page 46).

THE METENCEPHALON, METENCEPHALON

The metencephalon comprises the pons (ventral part) and the cerebellum (dorsal part).

THE PONS, PONS

The pons appears as a massive evagination on the ventral surface of brainstem sharply delimited from the medulla oblongata and the cerebral peduncles. Its ventral surface faces the clivus while the dorsal surface forms the upper portion of rhomboid fossa delimited inferiorly by the medullary stria of fourth ventricle.

External features

The external features of the pons are as follows (Fig. 9 and 11):

- the *medullopontine sulcus*, **sulcus bulbopontinus** that delimits the pons and medulla oblongata ventrally. The sulcus passes the *abducent nerve*, **nervus abducens** (between the pyramid and the medulla oblongata), the *facial nerve*, **nervus facialis** and the *vestibulocochlear nerve*, **nervus vestibulocochlearis** (the last two become evident on the surface of pons closer to the cerebellum);
- the *basilar sulcus*, **sulcus basilaris** that runs along the ventral surface. The sulcus houses the basilar artery;
- the *medullary stria of fourth ventricle*, **striae medullares ventriculi quarti** that cross the rhomboid fossa between the pons and medulla oblongata;

- the *middle cerebellar peduncle*, **pedunculus cerebellaris medius**, a paired whitish strand that runs to the cerebellum. Anterior to it, the lateral surfaces of pons give rise to the *facial nerves*, **nervi faciales**.

The nuclei and fibers of pons

A thick layer of transverse fibers that is well visible on cross-sectioned pons — the *trapezoid body*, **corpus trapezoideum** delimits two principal parts of pons: the *basilar part of pons* (the ventral portion) and *the tegmentum of pons* (the dorsal portion). The fibers of trapezoid body belong to auditory pathways and arise from the dorsal and ventral cochlear nuclei of vestibulocochlear nerve.

The basilar part of pons, pars basilaris pontis

This part resides ventrally from the trapezoid body. This part comprises the nuclei and fibers both longitudinal and transverse. Some fibers merely transit through the pons while other fibers synapse with the nuclei and proceed to the cerebellum.

The pons is the hub for the fibers that associate the cerebral cortex and the cerebellum.

This system comprises the nuclei and fibers as follows:

- the *pontine nuclei*, **nuclei pontis** small numerous nuclei that give fibers to the cerebellum;
- the *pontocerebellar fibers*, **fibrae pontocerebellares** that arise from the pontine nuclei and run to the opposite side thus forming transverse stria well visible on cross-sectioned pons. The ventral evagination of pons appears due to these fibers. The pontocerebellar fibers run through the middle cerebellar peduncles and terminate within its cortex;
- the *corticopontine fibers*, **fibrae corticopontinae** that run longitudinally. They arise from the cerebral cortex and terminate at the pontine nuclei. These nuclei thus, associate the cerebral cortex with the cerebellar cortex.

The pyramidal fibers

These fibers are as follows:

- the *corticospinal fibers*, **fibrae corticospinales** that transit the pons as quite thick bundles separated by the transverse fibers. From the pons, the fibers descend to the medulla oblongata;
- the *pontine corticonuclear fibers*, **fibrae corticonucleares pontis** that decussate within the pons and the medulla oblongata and synapse with the motor nuclei of related cranial nerves.

The pyramidal tracts as they transit through the pons give off some collateral fibers to the pontine nuclei.

The tegmentum of pons (the dorsal portion), tegmentum pontis

This portion is thinner than the ventral and occupies the dorsal part of

pons. It contains the following fibers and nuclei:

- the nuclei of cranial nerves situated closer to the surface of rhomboid fossa. They are the nuclei of trigeminal nerve, the abducent nerve, the facial nerve and the vestibulocochlear nerve (See 'Rhomboid fossa' section on page 46);
- the *superior olivary nucleus*, **nucleus olivarius superior** also of dentate shape, it resides within the lateral portion of tegmentum above the trapezoid body; the nucleus belongs to the auditory nuclei group;
- the *medial lemniscus*, **lemniscus medialis**, the bundle of sensory fibers that ascend from the medulla oblongata to the dorsal nucleus of thalamus. The lemniscus is accompanied by the anterior and the lateral spinothalamic tracts that run on the lateral side and by the fibers of sensory nuclei of trigeminal nerve (the trigeminal lemniscus). These fibers therefore form the principal sensory bundle of brainstem that transmits the impulses of exteroceptive and proprioceptive sensitivity;
- the *rubrospinal* and the *tectospinal* tracts that transit the tegmentum on the way down to the spinal cord.

THE CEREBELLUM, CEREBELLUM

The cerebellum belongs to metencephalon and resides posterior to the pons and the medulla oblongata above the fourth ventricle. Within the cranial cavity, it occupies the posterior cranial fossa. Superiorly it neighbors the occipital lobes of cerebral hemispheres being separated by the dura mater projection (the tentorium cerebelli). In the cerebellum, one can distinguish the superior (dorsal) surface, the inferior (ventral) surface, the anterior and the posterior borders.

The anterior border and the inferior surface feature broad excavation called the *vallecula of cerebellum*, **vallecula cerebelli** where the medulla oblongata and pons enter the cerebellum.

The parts of cerebellum

The cerebellum comprises two hemispheres and the vermis of cerebellum (Fig. 13):

- the *hemispheres of cerebellum*, **hemispheria cerebelli**, the larger lateral parts separated by deep *horizontal fissure*, **fissura horizontalis** that runs along the anterior border of each hemisphere; the fissure delimits superior and inferior parts of hemispheres;
- the *vermis of cerebellum*, **vermis cerebelli**, the unpaired narrow

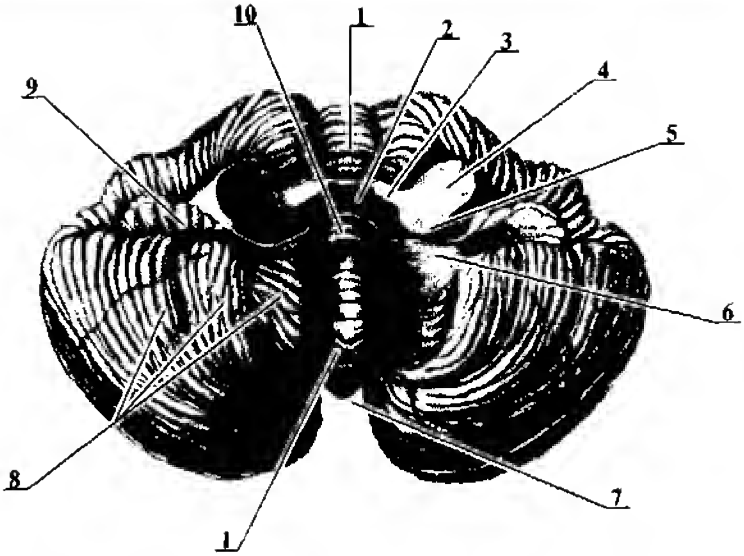

Fig. 13. External features of the cerebellum (anteroinferior view). 1 — vermis; 2 — vellum medullare superius; 3 — pedunculus cerebellaris superior; 4 — pedunculus cerebellaris medius; 5 — pedunculus cerebellaris inferior; 6 — pedunculus flocculi; 7 — vallecula cerebelli; 8 — lobuli cerebelli; 9 — flocculus; 10 — nodulus.

portion situated between the hemispheres.

Surface of the hemispheres and the vermis feature various *cerebellar fissures,* **fissurae cerebelli** delimit *lobes* **(lobi)**, *lobules* **(lobuli)** and *folia (gyri) of cerebellum* **(folia cerebelli)**.

The lobes of cerebellum

From the evolutional point of view, the cerebellum comprises anterior, posterior and flocculonodular lobes. The anterior and the posterior lobes are delimited by deep *primary fissure,* **fissura prima**.

1. The *flocculonodular lobe,* **lobus flocculonodularis** resides on the inferior surface of cerebellum. It is the oldest part, so-called *archicerebellum* (Lat. Id.). It consists of paired *flocculus* (Lat. Id.) and unpaired *nodule,* **nodulus** related to the vermis. A thin plate of white matter that expands between the flocculus and the nodule forms the *peduncle of flocculus,* **pedunculus flocculi**. Between the peduncles, one can distinguish a small *inferior medullary velum,* **velum medullare inferius** that belongs to the roof of fourth ventricle. The flocculus and the nodule are associated with the vestibular nuclei and are involved into body equilibrium control.

2. The *anterior lobe,* **lobus anterior**, it comprises the parts of cerebellum found anterior to the primary fissure namely a considerable portion of the vermis and related

anterior portions of hemispheres. The anterior lobe is the ancient part of cerebellum — the *paleocerebellum* (Lat. Id.) associated with the spinal cord via the anterior and the posterior spinocerebellar tracts and with the nuclei of posterior funiculus via the external arcuate fibers. This compartment controls muscle tone, coordinates the movements related to weight and inertia overcoming and controls body equilibrium both static and dynamic.

3. The *posterior lobe*, **lobus posterior** comprises the parts found posterior to the primary fissure namely the smaller portion of vermis and the most part of hemispheres. The posterior lobe is the newest among the parts and constitutes the *neocerebellum* (Lat. Id.). This part develops from associations with the cerebral cortex (via the corticopontocerebellar tracts). It controls both voluntary and automated movements comparing the signals from cerebral cortex with peripheral signals.

Internal features of cerebellum

The folia of cerebellum are covered with grey matter that constitutes the *cerebellar cortex*, **cotex cerebelli**. Deeper white matter contains the cerebellar nuclei. Sagittal section reveals specific treelike arrangement of white and grey matter thus called the *arbor vitae* (Lat. Id.).

The nuclei of cerebellum

The white matter contains the nuclei as follows:

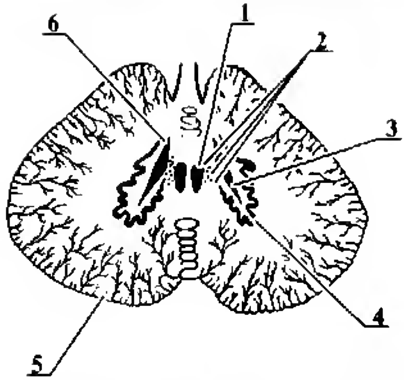

Fig. 14. Horizontal section of the cerebellum. 1 — nucl. fastigii; 2 — nucl. globosus; 3 — nucl. emboliformis; 4 — nucl. dentatus; 5 — cortex cerebelli; 6 — hilum nucl. dentati.

- the *dentate nucleus*, **nucleus dentatus** the largest nucleus that resides within the hemispheres (related to the neocerebellum). It appears as wavy thin plate of grey matter with convex area directed posterolaterally. Medial area features the *hilum of dentate nucleus*, **hilum nuclei dentati** that passes the dentatorubral fibers that run through the superior cerebellar peduncles and reach the red nucleus. The hilum also passes the fibers that ascend to the thalamus;
- the *emboliform nucleus*, **nucleus emboliformis** situated medially;
- the *globose nucleus*, **nucleus globosus** situated medially from the emboliform nucleus;
- the *fastigial nucleus*, **nucleus fastigii** situated within the vermis along the midline.

The cerebellar peduncles

The cerebellum connects to other brain compartments by means of white matter bundles called the cerebellar peduncles.

1. The *inferior cerebellar peduncles*, **pedunculi cerebellares inferior** associate the cerebellum with medulla oblongata. They contain the following fibers:

- the *posterior spinocerebellar tract*, **tractus spinocerebellaris posterior** (Flechsig's tract) that runs from the spinal cord to the cerebellar cortex (portion of vermis related to anterior lobe);
- the *olivocerebellar tract*, **tractus olivocerebellaris** that runs from the inferior olivary nucleus to the dentate nucleus;
- the *external arcuate fibers*, **fibrae arcuatae externae** that arise from the cuneate and the gracile nuclei and reach the cortex of vermis (related to the anterior lobe);
- the *vestibulocerebellar fibers*, **fibrae vestibulocerebellares** that run from the vestibular nuclei to the fastigial nuclei.

2. The *middle cerebellar peduncles*, **pedunculi cerebellares medii** associate the cerebellum with the pons. They contain the pontocerebellar fibers that run from the pontine nuclei to the cortex of posterior lobe. The pontine nuclei in turn are associated with the cerebral cortex via the corticopontine fibers. This two-level pathway associates the cerebral cortex with the cerebellar cortex (**neocerebellum**).

3. The *superior cerebellar peduncles*, **pedunculi cerebellares superiors** associate the cerebellum with the midbrain and the thalamus. They contain the following fibers:

- the *dentatorubral fibers*, **fibrae dentatorubrales** that run from the dentate nucleus to the red nucleus. They constitute the primary efferent pathway that transmits impulses from the cerebellum;
- some fibers from the dentate nucleus ascend to the thalamus and further to the cerebral cortex. These fibers transmit the impulses from the cerebellum to the cerebral cortex
- the *anterior spinocerebellar tract*, **tractus spinocerebellaris anterior** (Gowers' tract) that arises from the spinal cord on each side, transits through the medulla oblongata and the pons, decussates within the superior medullary velum and enters the contralateral superior cerebellar peduncle to reach the cortex of vermis (related to the anterior lobe).

The *superior medullary velum*, **velum medulare superius** expands between the superior cerebellar peduncles. It passes thin roots of the *trochlear nerve*, **nervus trochlearis** – the fourth pair of cranial nerves.

THE RHOMBOID FOSSA, FOSSA RHOMBOIDEA

The rhomboid fossa appears as diamond shaped excavation that resides on the dorsal surfaces of the medulla oblongata and the pons. It is delimited by the superior and inferior cerebellar peduncles and features four angles — superior, inferior and two lateral angles.

The inferior angle is partially closed with the *obex* (Lat. Id.), which covers the opening of the central canal of spinal cord. The upper angle features the opening of the *aqueduct of midbrain (cerebral aqueduct)*, **aqueductus mesencephali (cerebri)**. The lateral angles form the lateral recesses of fourth ventricle.

Relief of the rhomboid fossa

On the surface of fossa, one can see the following:

- the *median sulcus*, **sulcus medianus** that runs midline;
- the *medial eminence*, **eminentia medialis**, an arched longitudinal elevation that runs along the median sulcus. Laterally it is bounded by the *sulcus limitans* (Lat. Id.);
- the *medullary stria of fourth ventricle*, **striae medullares ventriculi quarti** that delimit the pons and the medulla oblongata;
- the *superior fovea*, **fovea superior**, the upper extension of the sulcus limitans;
- the *inferior fovea*, **fovea inferior** the inferior extension of the sulcus limitans;
- the *facial colliculus*, **colliculus facialis** a small elevation of the medial eminence situated right above the medullary striae;
- the *vestibular area*, **area vestibularis** that occupies each lateral angle of the fossa;
- the *locus caeruleus* (Lat. Id.) a bluish area situated above the vestibular area and laterally from the sulcus limitans;
- the *hypoglossal trigone*, **trigonum nervi hypoglossi** a triangular area on the inferior portion of the medial eminence with its base directed to the medullary stria;
- the *vagal trigone*, **trigonum nervi vagi** found laterally and inferiorly from the latter.

The nuclei of cranial nerves

The pons and the medulla oblongata house the nuclei of cranial nerves 5 through 12 that can be mapped on the area limited to the rhomboid fossa.

The cranial nerves feature sensory, motor and autonomic nuclei.

Arrangement of the nuclei

Generally, the nuclei of cranial nerves are arranged similarly to those of spinal cord yet one should keep in mind that during embryonic development the neural tube of respective area opens so that the posterior horns move apart. The central canal in turn transforms into the common cavity of the fourth ventricle. As the result of

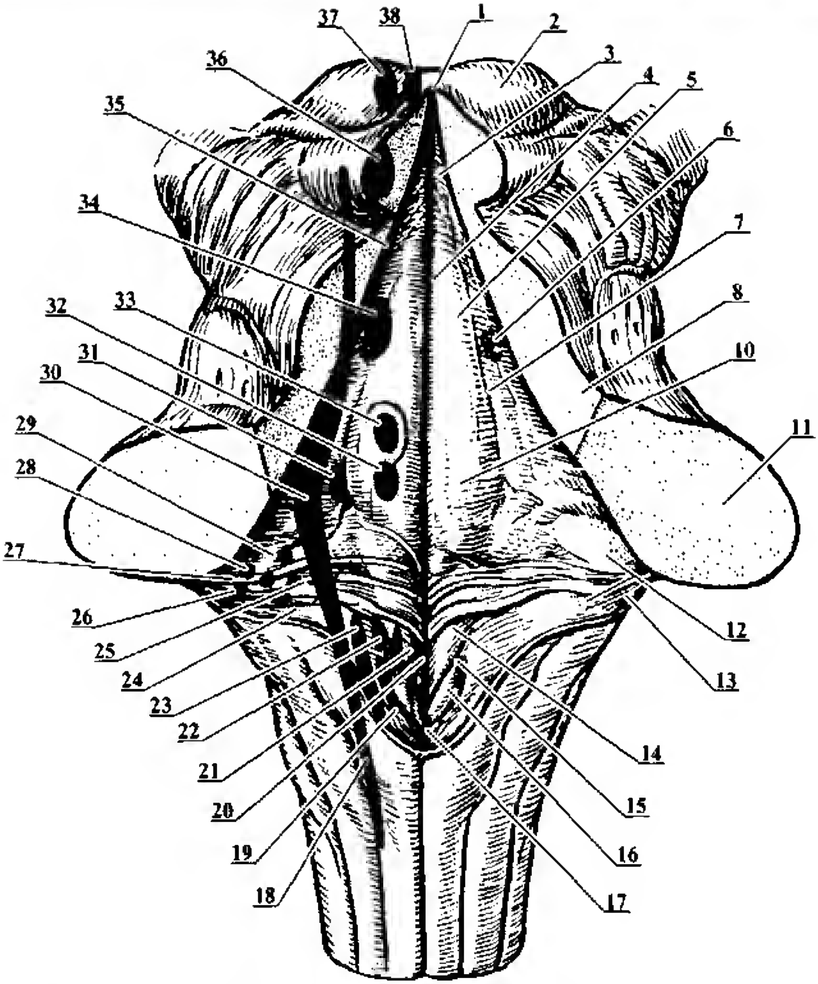

Fig. 15. The rhomboid fossa, its relief with mapped nuclei of cranial nerves (the motor nuclei are red, the sensory are blue and the parasympathetic are green). 1 — aqueductus cerebri; 2 — tectum mesencephali; 3 — fovea superior; 4 — sulcus medianus; 5 — eminentia medialis; 6 — locus caeruleus; 7 — sulcus limitans; 8 — pedunculus cerebellaris superior; 9 — colliculus facialis; 10 — striae medullares ventriculi quarti; 11 — pedunculus cerebellaris medius; 12 — area vestibularis; 13 — pedunculus cerebellaris inferior; 14 — trigonum n. hypoglossi; 15 — fovea inferior; 16 — trigonum n. vagi; 17 — obex; 18 — nucl. spinalis n. trigemini; 19 — nucl. dorsalis n. vagi; 20 — nucl. n. hypoglossi; 21 — nucl. ambiguus; 22 — nucl. salivatorius inferior; 23 — nucl. tracti solitarii; 24 — nucl. vestibularis inferior; 25 — nucl. vestibularis medialis; 26 — nucl. cochlearis dorsalis; 27 — nucl. vestibularis lateralis; 28 — nucl. cochlearis ventralis; 29 — nucl. vestibularis superior; 30 — nucl. principalis n. trigemini; 31 — nucl. salivatorius superior; 32 — nucl. n. facialis; 33 — nucl. n. abducentis; 34 — nucl. motorius n. trigemini; 35 — nucl. mesencephalicus n. trigemini; 36 — nucl. n. trochlearis; 37 — nucl. n. oculomotorii; 38 — nucl. accessorius n. oculomotorii.

this, the column of sensory nuclei appears on the lateral side of the brainstem and the column of motor nuclei appears medially. The intermediate zone contains the autonomic nuclei. Unlike the spinal cord, the brainstem features separate nuclei related to a specific cranial nerve.

The motor nuclei

The pons houses the motor nuclei of the 5th, the 6th and the 7th cranial nerves related to the upper portion of rhomboid fossa. They are:

1) the *motor nucleus of trigeminal nerve*, **nucleus motorius nervi grigemini** embedded into the upper portion of the tegmentum of pons on the level of *superior fovea*, **fovea superior**. The nucleus gives rise to the motor fibers that supply masticatory muscles, the muscles of oral cavity floor and the tensor veli palatini;

2) the *nucleus of abducens nerve*, **nucleus nervi abducentis** embedded into the tegmentum of pons closer to the medulla oblongata. The nucleus is related to the facial colliculus formed of the fibers of facial nerve (that loop around the nucleus of abducens nerve). This nucleus is responsible for supplying of the lateral rectus;

3) the *motor nucleus of facial nerve*, **nucleus nervi facialis** found on the same level as previous but deeper within the tegmentum of pons. Its fibers arch in posteromedial direction and loop around the nucleus of abducens nerve. Then they proceed ventrally and quit the pons to reach the mimic muscles;

The medulla oblongata houses two motor nuclei. One of them gives rise to the 9th, 10th and 11th pairs of cranial nerves and another – to the 12th pair. They are like the following:

1) the *nucleus ambiguus* (Lat. Id.) embedded into the reticular formation of the lower portion of medulla oblongata on the level of the *inferior fovea*, **fovea inferior**. The nucleus gives rise to motor fibers of the glossopharyngeal, the vagus and the accessory nerves. These fibers supply the striated muscles of the soft palate, the pharynx, the larynx and the upper one third of esophagus;

2) the *nucleus of hypoglossal nerve*, **nucleus nervi hypoglossi** embedded into the medulla oblongata on the level of hypoglossal trigone. Its fibers supply all muscles of tongue.

Clinical applications

The cortex of precentral gyrus gives rise to the corticonuclear fibers that decussate within the brainstem and synapse with the nuclear cells of the opposite side. Most of the nuclei also feature non-decussated pathways. The nuclei of the facial and the hypoglossal nerves nevertheless feature only non-decussated pathways. Thus, unilateral injury to the cortex or the pyramidal pathways results in paralysis of the mimic muscles (the facial nerve) and the muscles of tongue (the hypoglossal nerve), while the masticatory muscles (the trigeminal nerve), the pharyngeal muscles and the muscles of larynx (the nucleus ambiguus) retain functionality.

The sensory nuclei

The pons houses the sensory nuclei of trigeminal and vestibulocochlear nerves as follows:

1) the *principal sensory nucleus of trigeminal nerve*, **nucleus principalis nervi trigemini** situated within the tegmentum of pons laterally from the motor nucleus of the same nerve on the level of locus caeruleus. It accepts the sensory fibers that transmit the impulses of proprioceptive and tactile sensitivity. The fibers that arise from the nucleus decussate and join the medial lemniscus to reach the thalamus (its ventrolateral nucleus);

2) the *cochlear nuclei*, **nuclei cochleares** that belong to the cochlear part of the vestibulocochlear nerve. There are two cochlear nuclei: the *posterior (dorsal) cochlear nucleus*, **nucleus cochlearis posterior** situated closer to the surface of the rhomboid fossa on the level of vestibular area and the *anterior (ventral) cochlear nucleus*, **nucleus cochlearis anterior** situated deeper on the same level. Both nuclei give rise to the fibers of the trapezoid body that become continuous with the lateral lemniscus;

3) the *vestibular nuclei*, **nuclei vestibulares** that constitute the vestibular part of the vestibulocochlear nerve. There are four vestibular nuclei that occupy the dorsal portion of the pons on the level of the vestibular area. The nuclei are as follows: the *superior nucleus* (Bechterew's nucleus), the *inferior nucleus* (Roller's nucleus), the *medial nucleus* (Schwalbe's nucleus) and the *lateral nucleus* (Deiters' nucleus). They receive impulses from receptors of the vestibule and the semicircular canals responsible for spatial orientation of head;

The medulla oblongata houses two sensory nuclei of the cranial nerves:

1) the *spinal nucleus of trigeminal nerve*, **nucleus spinalis nervi trigemini**, rather elongated, it resides within the dorsolateral portion of medulla oblongata and descends to the spinal cord to become continuous with the gelatinous substance of posterior grey column. The cells of nucleus accept the fibers of *spinal tract of trigeminal nerve* **(tractus spinalis nervi trigemini)** that descend from the pons and also reach the posterior grey columns of spinal cord. The fibers are responsible for pain and temperature sensitivity of skin and mucous membranes of head and are connected with the fifth pair of cranial nerves. The fibers that arise from the nucleus decussate and join the medial lemniscus to reach the thalamus;

2) the *nucleus of solitary tract*, **nucleus tractus solitarii** also elongated, it resides within the dorsal portions of medulla oblongata laterally from the vagal trigone. This nucleus accepts the fibers from the 7^{th}, the 9^{th} and the 10^{th} pairs of cranial nerves. These fibers enter the brainstem and descend as so-called *solitary tract*, **tractus solitarius**. The fibers related to the solitary tract carry gustatory impulses from the tongue, oral cavity walls epiglottis and the pharynx. The axons of nucleus also decussate and enter the medial lemniscus to reach the thalamus as well.

Autonomic nuclei

The portions of the pons and the medulla oblongata limited to the rhomboid fossa contain two small autonomic nuclei associated with the 7th and the 9th cranial nerves and one large nucleus associated with the 10th cranial nerve. The nuclei are like the following

1) the *superior salivatory nucleus*, **nucleus salivatorius superior** embedded into the reticular formation of the pons laterally from the motor nucleus of facial nerve. The parasympathetic fibers from this nucleus belong to the facial nerve; they supply the lacrimal, sublingual and submandibular glands as well as the glands of nasal and palatine mucosa;

2) the *inferior salivatory nucleus*, **nucleus salivatorius inferior** embedded into reticular formation of the medulla oblongata laterally from the *nucleus ambiguus*. The nucleus is related to the upper portion of vagal trigone. The parasympathetic fibers from this nucleus join the glossopharyngeal nerve and supply the parotid gland;

3) the *dorsal nucleus of vagus nerve*, **nucleus dorsalis nervi vagi** the biggest autonomic nucleus embedded into the medulla oblongata at level of vagal trigone. The axons of nucleus join the vagus nerve and provide parasympathetic nerve supply to cervical, thoracic and abdominal viscera except for the lesser pelvis. Stimulation to these cells results in decelerated heart rate, bronchial constriction, increased intestinal peristalsis and increased secretion of digestive glands. The dorsal nucleus of vagus nerve is tightly associated with the subthalamic region, the nucleus of solitary tract and the reticular formation. These associations regulate circulation, respiration and digestion together with some complex visceral reflexes like vomiting, deglutition etc.

THE FOURTH VENTRICLE, VENTRICULUS QUARTUS

The fourth ventricle is the cavity of rhombencephalon. It resembles the tent with the apex called *fastigium* (Lat. Id.) and two lateral extensions called the *lateral recesses*, **recessus lateralis.**

The walls of fourth ventricle

The floor of fourth ventricle constitutes the rhomboid fossa while the *roof of fourth ventricle*, **tegmen ventriculi quarti** appears to be more complex and features the parts as follows:

- the *superior medullary velum*, **velum medullare superius** that expands between the superior cerebellar peduncles;
- the *inferior medullary velum*, **velum medullare inferius** that expands between the peduncles of flocculus;
- the *choroid membrane*, **tela choroidea** derived from the pia mater. Superiorly, it adheres to the superior medullary velum and inferiorly – to the medulla oblongata. The membrane features the *choroid plexus*, **plexus choroideus** that produces the cerebrospinal fluid.

Communications of the fourth ventricle

The choroid membrane that invests the fourth ventricle features

three openings that communicate the cavity with the subarachnoid space. They are as follows:

- the *median aperture*, **aperture mediana** (of Magendie), unpaired, it resides in the center of choroid membrane;
- the *lateral aperture*, **apertura lateralis** (of Luschka), paired, it is related to the lateral recesses.

The cerebral aqueduct (aqueduct of Sylvius) communicates the cavities of the third and the fourth ventricles; inferiorly, the fourth ventricle becomes continuous with the central canal of fourth ventricle.

Clinical applications

The apertures of the fourth ventricle draw special attention as far as they provide drainage for the cerebrospinal fluid. Inflammation of meninges (meningitis) may result in obliteration of the apertures with possible development of hydrocephaly due to increased cerebral pressure.

THE MIDBRAIN, MESENCEPHALON

The midbrain comprises the *tectal (quadrigeminal) plate*, **lamina tecti (quadrigemina)** situated dorsally (it forms the tectum of midbrain) and the cerebellar peduncles situated ventrally. The compartments are delimited by the cerebral aqueduct.

THE AQUEDUCT OF MIDBRAIN (CEREBRAL AQUEDUCT), AQUEDUCTUS MESENCEPHALI (CEREBRI)

The cerebral aqueduct appears as narrow passage (1 mm of diameter) 1.5-2 cm long that provides communication between the third and the fourth ventricles. The aqueduct is surrounded by the *central grey substance*, **substantia grisea centralis** with the autonomic regulatory cells featured (Fig. 16).

THE CEREBRAL PEDUNCLES, PEDUNCULI CEREBRI

The cerebral peduncles appear as paired strand rather thick that runs slantwise and ventrally in direction of the diencephalon. The left and the right peduncles move apart to bound the *interpeduncular fossa*, **fossa interpeduncularis** with featured *posterior perforated substance*, **substantia perforata posterior**. The *oculomotor nerve*, **nervus oculomotorius** becomes evident in this area.

Each cerebral peduncle features the ventral portion called the *base of peduncle*, **basis peduculi** and the dorsal portion called the *tegmentum of midbrain*, **tegmentum mesencephali**. The two portions are delimited by the substantia nigra.

The *substantia nigra* (Lat. Id.) is found between the base and the teg-

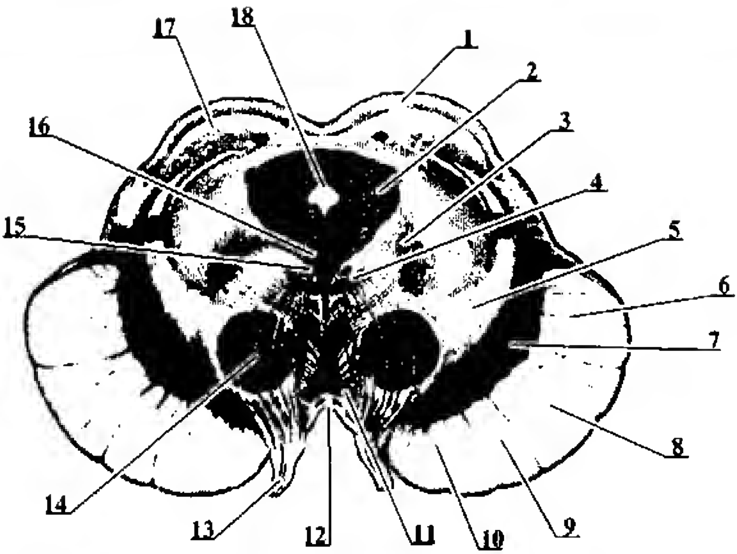

Fig. 16. The midbrain (cross section through the superior colliculi). 1 – colliculus superior; 2 – substantia grisea centralis; 3 – formatio reticularis; 4 – fasciculus longitudinalis medialis; 5 – lemniscus medialis; 6 – fibrae parietotemporopontinae; 7 – substantia nigra; 8 – fibrae corticospinales; 9 – fibrae corticonucleares; 10 – fibrae corticopontinae; 11 – tractus rubrospinalis; 12 – fossa interpeduncularis; 13 – n. oculomotorius; 14 – nucl. ruber; 15 – nucl. n. oculomotorii; 16 – nucl. accessorius n. oculomotorii; 17 – nucl. proprius colliculi superioris; 18 – aqueductus cerbri.

mentum. It runs all along the peduncle i.e. from the pons to the diencephalon. Frontal section of the midbrain reveals the substance as black thin crescent-shaped plate. The featured neurons contain black pigment – the melanin. The substantia nigra belongs to subcortical motor nuclei of the extrapyramidal system that is responsible for plastic tonus of the muscles. The neurons of the substantia nigra communicate with the basal nuclei of telencephalon and supply one of the most important neurotransmitters – the dopamine, which is vital for basal nuclei functioning. Secretory insufficiency of the substantia nigra results in Parkinson's disease manifested as uncontrolled muscle tremor, muscle rigidity etc.

THE TEGMENTUM OF MIDBRAIN, TEGMENTUM MESENCEPHALI

The *tegmentum of midbrain*, **tegmentum mesencephali** resides dorsally from the substantia nigra and reaches the cerebral aqueduct. It features the nuclei and fibers like the following:

The *red nucleus*, **nucleus ruber**, is one of the biggest nuclei of midbrain (length – 15 mm, diameter – 6 mm and volume – 136 mm^3). Sectioned

nucleus has rounded shape. Its upper end reaches the diencephalon and the lower end reaches the level of superior colliculi. Pink color of the nucleus as observed on fresh sample is specified by abundant blood supply and dense capillary network. The red nucleus is the most important extrapyramidal nucleus. It is tightly associated with the cerebellum, which sends the efferent impulses via the dentatorubral fibers (they pass through the superior cerebellar peduncles). Apart from this, the rd nucleus features associations with the cerebral cortex, the basal nuclei of telencephalon, other subcortical nuclei and the spinal cord. The red nuclei regulate muscle tonus and automated movements' precision.

The *rubrospinal tract*, **tractus rubrospinalis** is the tract that arises from the inferior end of the red nucleus. Its fibers decussate and descend to the lateral funiculus of spinal cord (upon traversal of the pons and medulla oblongata) where the fibers synapse with the motor nuclei of anterior grey columns. A good share of the fibers terminates within the reticular formation of brainstem.

The nuclei of cranial nerves

The tegmentum of midbrain houses the nuclei of the 3rd and the 4th cranial nerves that neighbor the cerebral aqueduct anteriorly. The nuclei are like the following:

- the *nucleus of oculomotor nerve*, **nucleus nervi oculomotorii**, the motor nucleus situated below the cerebral aqueduct on the level of superior colliculi; the nucleus is responsible for supplying of most of the extra-ocular muscles and the *levator palpebrae superioris;*
- the *accessory nucleus of oculomotor nerve*, **nucleus accessorius nervi oculomotorii** (of Yakubovich), the parasympathetic nucleus situated medially from the latter. Its fibers join the oculomotor nerve and reach the ciliary ganglion, which in turn supplies the *ciliary muscle* and the *sphincter pupillae*;
- the *nucleus of trochlear nerve*, **nucleus nervi trochlearis**, the motor nucleus also found below the cerebral aqueduct yet on the level of inferior colliculi. The trochlear nerve supplies solely the *superior oblique*.

The medial longitudinal fasciculus

The motor nuclei related to the extra-ocular muscles, namely the oculomotor, the trochlear and the abducent nerves, feature specific association fibers called the *medial longitudinal fasciculus*, **fasciculus longitudinalis medialis**. The fasciculus descends through the pons and the medulla oblongata to reach the upper portions of the anterior grey columns with featured motor neurons (that give rise to the cervical plexus, which supplies the cervical muscles and the muscles of head). The fasciculus is involved into extremely fine coordination of movements of eyes and head; it is also responsible for fixation reflex – an ability to maintain the fixation point on the item focused while moving the head.

The *lateral lemniscus*, **lemniscus lateralis** is the bundle of fibers that arises from the anterior and the posterior cochlear nuclei that belong to the vestibulocochlear nerve. The fibers then run to the opposite side, form the trapezoid body and loop upwards to enter the tegmentum of cerebral peduncle. Here they run laterally, fairly close to cerebral surface in the area of the *trigone of lateral lemniscus*, **trigonum lemnisci lateralis**. The lateral lemniscus transmits the auditory *impulses and terminates at the nuclei* of the superior colliculi; the auditory tract further proceeds to the medial geniculate bodies.

The *medial lemniscus* and the *spinothalamic tract* just traverse the tegmentum on the way to destination point.

The *reticular formation*, **formatio reticularis** occupies medial position within the tegmentum. It becomes continuous with the same compartment of diencephalon.

THE BASE OF PEDUNCLE, BASIS PEDUNCULI CEREBRI

This ventral portion contains the descending pathways as follows:

1) the *corticospinal fibers*, **fibrae corticospinales**;

2) the *corticonuclear fibers*, **fibrae corticonucleares**;

3) the *corticopontine fibers*, **fibrae corticopontinae**;

The pyramidal fibers occupy the central portion of base, whilst the corticopontine fibers run laterally and medially.

THE TECTAL PLATE, LAMINA TECTI

This dorsal portion of the midbrain comprises four colliculi – two superior and two inferior (Fig. 11):

- the *superior colliculus*, **colliculus superior**, a paired eminence, which is continuous with the *brachium of superior colliculus*, **brachium colliculi superioris**, which in turn runs to the lateral geniculate body of the diencephalon *(metathalamus). The superior* colliculi house the nuclei of superior colliculus – the subcortical visual centers;
- the *inferior colliculus*, **colliculus inferior** also paired, it is continuous with the *brachium of inferior colliculus*, **brachium colliculi inferioris** that reaches the medial geniculate body. The inferior colliculi house the *nuclei of inferior colliculi (the central and the external)*, **nuclei colliculi inferiors (centralis et externus)**, which are the subcortical auditory centers.

The nuclei housed by the colliculi give rise to the tectospinal tract that decussates within the tegmentum of midbrain and eventually appears within the anterior funiculus of the spinal cord. The tract terminates within the anterior grey columns with synapses on the motor nuclei. The nuclei of colliculi are responsible for reflexes associated with sudden sound and visual stimuli.

THE DIENCEPHALON, DIENCEPHALON

The diencephalon comprises the thalamus (the biggest portion), the epithalamus, the metathalamus and the hypothalamus. The cavity of diencephalon is represented with the third ventricle.

In the area of the midbrain and the telencephalon, the longitudinal axis of brain exhibits rather an expressed anterior flexure at angle of about 110°. Therefore, the terms 'ventral' and 'dorsal' here correspond to 'superior' and 'inferior' whilst 'anterior' and 'posterior' correspond to frontal and occipital poles of the cerebral hemispheres.

THE THALAMUS, THALAMUS[1]

The thalamus appears as paired ovoid mass that developed from relatively big aggregation of grey matter. It resides anteriorly from the tectal plate below the fornix and the corpus callosum (Fig. 11, 17). The dorsal and the medial surfaces of the thalamus are free whilst the lateral and the ventral adhere to the neighboring structures. The thalamus comprises the ventral and the dorsal compartments delimited by the hypothalamic sulcus.

THE DORSAL THALAMUS, THALAMUS

The *dorsal thalamus*, **thalamus** (the portion usually referred to as thalamus *per se*) has features as follows:

- the *anterior thalamic tubercle*, **tuberculum anteruis thalami** found on its anterior end;
- the *pulvinar*, **pulvinar thalami**, its posterior thickened portion;
- the *sulcus terminalis* (Lat. Id.) that delimits the thalamus from the caudate nucleus (BNA);
- the *hypothalamic sulcus*, **sulcus hypothalamicus** that runs along the medial surface of thalamus. It delimits the dorsal thalamus from the ventral;
- the *interthalamic adhesion*, **adhesio interthalamica**, a thin layer that connects the two thalami;
- the *stria medullaris of thalamus*, **stria medullaris thalami**, a thin whitish stria that runs between the superior and medial surfaces of the thalamus in direction of the habenular trigone.

The nuclei of dorsal thalamus

The dorsal thalamus consists mostly of grey matter separated by thin layers of white matter so one can distinguish numerous (over 40) nuclei. The most important groups of nuclei are like the following:

- the *anterior nuclei of thalamus*, **nuclei anteriores thalami** related to the olfactory pathways;

[1] the term 'optic thalamus' was considered inconsistent for it is a relay center for almost all kinds of sensory impulses

- the *pulvinar nuclei*, **nuclei pulvinares** found within respective compartment. They are related to the optic pathways;
- the *ventral lateral complex*, **nuclei ventrales laterales** that accepts the fibers from the medial lemniscus;
- the *medial nuclei of thalamus*, **nuclei mediales thalami** related to association areas of the cerebral cortex.

The dorsal thalamus as the subcortical sensory center

The thalamic nuclei accept the fibers of the medial lemniscus that transmits pain, temperature, tactile, proprioceptive, interoceptive, optic and olfactory impulses. The thalamus is the relay center for sensory data, the hub on the way to the cerebral cortex. The thalamus gives rise to the thalamocortical pathways and the cortex sends regulatory impulses back to the thalamus. The thalamus features extensive connections with the corpus striatum and the hypothalamus. The thalamus is the center of primitive emotions and affective states; pain sensation arises on this level as well. Any kind of damage results in polymorphic picture including sensitivity loss, severe pain, forced laughter and crying, anxiety and fear (the symptoms are site dependent).

THE VENTRAL THALAMUS, SUBTHALAMUS

The *subthalamus* or *ventral thalamus*, **subthalamus** resides between the hypothalamic sulcus and the hypothalamus. This area is merely a continuation of the tegmentum of midbrain. The area features the following nuclei:

- the *subthalamic nucleus*, **nucleus subthalamicus** (nucleus of Luys), one of the extrapyramidal centers;
- the *reticular nuclei of thalamus*, **nuclei reticulares thalami** related to the reticular formation;
- the *red nucleus*, **nucleus ruber** that reaches the area from the tegmentum of midbrain; it is also one of the extrapyramidal centers;
- the *substantia nigra* (Lat. Id.), another extrapyramidal center also continuous from the tegmentum of midbrain.

THE METATHALAMUS, METATHALAMUS

The *metathalamus* (Lat. Id.) comprises the following portions:

- the *medial geniculate body*, **corpus geniculatum mediale** that resides below the pulvinar; its nucleus belongs to the subcortical auditory centers. It accepts the fibers from the inferior colliculi and some fibers from the lateral lemniscus;
- the *lateral geniculate body*, **corpus geniculatum laterale** found laterally from the latter; its nucleus belongs to the subcortical visual centers. It accepts a good lot of the fibers from the optic tract.

THE EPITHALAMUS, EPITHALAMUS

The *epithalamus* (Lat. Id.) comprises the following structures:

- the *pineal gland*, **glandula pinealis**, an unpaired endocrine gland situated between the superior colliculi of the tectal plate;
- the *habenula* (Lat. Id.), the white matter projections that connect the pineal gland to the dorsal thalamus;
- the *habenular commissure*, **commissura habenularum** that connects the two habenulae anterior to the pineal gland;
- the *habenular trigone*, **trigonum habenulare**, a triangular extension of the habenula next to the thalamus. The habenula features the nucleus related to the olfactory centers;
- the *posterior (epithalamic) commissure*, **commissura posterior (epithalamica)** situated anterior and inferior to the pineal gland around the posterior wall of the third ventricle. It associates the pulvinars and the colliculi of tectal plate.

THE HYPOTHALAMUS, HYPOTHALAMUS

This area resides ventrally from the thalamus and forms the floor of the third ventricle (Fig. 17). It comprises the portions as follows:

- the *preoptic area*, **area preoptica** situated anterior to the optic chiasm;
- the *optic chiasm*, **chiasma optica** an incomplete decussation formed by the fibers of the optic nerve; it resides anterior to the tuber cinereum;
- the *optic tract*, **tractus opticus**, the fibers that arise from the optic chiasm. They loop around the cerebral peduncles and terminate within the lateral geniculate bodies (larger portion) and within the superior colliculi of tectal plate;
- the *tuber cinereum* (Lat. Id.), a small unpaired eminence situated posterior to the optic chiasm. It is an inferior extension of the third ventricle continuous with the infundibulum;
- the *infundibulum* (Lat. Id.), the narrowed inferior portion of the tuber cinereum continuous with the pituitary gland;
- the *neurohypophysis* (Lat. Id.), the posterior lobe of the pituitary situated within the hypophysial fossa of Turkish saddle. Superiorly it is covered by the dura matter projection called the *diaphragma sellae* with featured opening for the infundibulum. Generally, the pituitary has two lobes – the anterior (adenohypophysis) and the posterior (neurohypophysis) (See Vol. 2);
- the *mammillary body*, **corpus mammillare**, a paired eminence situated posterior to the tuber cinereum. The nuclei of the mammillary bodies constitute the subcortical olfactory centers connected to the columns of fornix.

The nuclei of hypothalamus

The hypothalamus features numerous nuclei (over 30) that group into four areas like the following:

1) the *anterior hypothalamic area* that houses the *supra-optic* and *paraventricular nuclei* (**nuclei supraopticus et paraventricularis**);

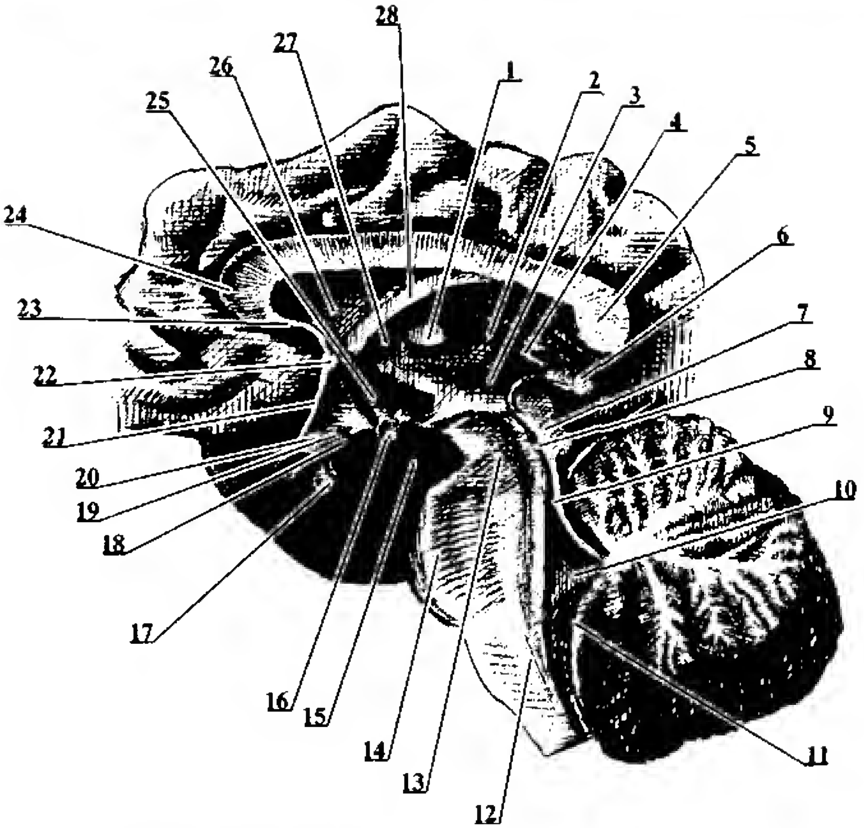

Fig. 17. The midbrain (sagittal section). 1 — adhesio interthalamica; 2 — thalamus; 3 — sulcus hypothalamicus; 4 — comissura cerebri posterior; 5 — corpus callosum (splenium); 6 — epiphysis (corpus pineale); 7 — tectum mesencephali; 8 — aqueductus mesencephali; 9 — vellum medullare superius; 10 — ventriculus IV; 11 — vellum medullare inferius; 12 — medulla oblongata; 13 — pedunculus cerebri; 14 — pons; 15 — n. oculomotorius (III); 16 — corpora mamillaria; 17 — hypophysis; 18 — tuber cinereum; 19 — recessus infundibuli; 20 — chiasma optica; 21 — lamina terminalis; 22 — comissura cerebri anterior; 23 — rostrum corporis callosi; 24 — genu corporis callosi; 25 — columna fornicis; 26 — septum pellucidum; 27 — corpus fornicis; 28 — foramen interventriculare.

2) the *posterior hypothalamic area* that comprises the nuclei of mammillary bodies;

3) the *dorsal hypothalamic area* thatcomprises several dorsal nuclei;

4) the *intermediate hypothalamic area* that comprises numerous small nuclei like the *infundibular nuclei*, the *lateral tuberal nuclei*, the *dorsomedial nuclei*, the *ventromedial nuclei*, the *dorsal nucleus* etc.

The neurons of some nuclei have an ability to secrete hormones called neurosecretion. The hormones se-

creted by the supra-optic and the paraventricular nuclei proceed to the neurohypophysis via the hypothalamo-hypophyseal tract (by means of axonal transport) and diffuse to blood flow through the capillaries. The hormones produced by other nuclei reach the anterior lobe via the hypothalamo-hypophyseal portal system where they influence the secretory cells of the pituitary. Therefore, the hypothalamic nuclei and the pituitary constitute the hypothalamo-hypophyseal system that provides neurohumoral regulation of all tissues and organs.

The hypothalamus as superior autonomic regulatory center

The hypothalamic nuclei regulate all kinds of metabolism (water, salts, carbohydrates, proteins and lipids) thus providing homeostasis maintenance. The hypothalamus contains regulatory centers of blood circulation, respiration, digestion, sexuality, thermoregulation, etc. Electrical stimulation of the hypothalamic nuclei results in variety of manifestations like hunger, satiety, thirst, arousal, temper disorders, sleepiness or wakefulness. In absence of visible injures, the hypothalamic disorders manifest themselves as deranged metabolic processes and impaired functioning of the viscera.

The afferent impulses from the viscera and the blood vessels reach the hypothalamus via the autonomic nerves and reticular formation of the brainstem. Interoceptive impulses from the spinal cord are likely to be transmitted via the spinothalamic tracts and spinal reticular formation. Apart from this, this area receives the impulses from the somatosensory nuclei of the hippocampus, amygdaloid bodies and the cerebral cortex.

Efferent communications of the hypothalamus are provided by the reticular formation of the brainstem associated with the salivatory nuclei and the dorsal nucleus of vagus nerve. Apart from this, the impulses from the hypothalamus are transmitted via the reticulospinal fibers to sympathetic and parasympathetic spinal nuclei. The tracts to the autonomic centers synapse (and thus interrupt) on different levels that allows various incoming data to enter the line in those relay points.

The hypothalamus provides communication between the interior and the ambient so far as the signals from both sources result in reactions of the endocrine system; nervous regulation of viscera activities is also performed by the hypothalamus. The hypothalamus thus is evident in integrity of the nervous and the endocrine systems.

THE THIRD VENTRICLE, VENTRICULUS TERTIUS

The third ventricle is the cavity of the diencephalon enclosed between the two thalami (Fig. 17).

The walls of the third ventricle are like the following:

- the *lateral walls* made up of the medial surfaces of the thalami;
- the *anterior wall* made up of the columns of fornix, the anterior

commissure and the lamina terminalis;
- the *posterior wall* made up of the posterior commissure and the habenular commissure with the *suprapineal recess*, **recessus suprapinealis** found superiorly;
- the *inferior wall* made up of the optic chiasm, the optic tracts, the tuber cinereum with the infundibulum and the mammillary bodies; the inferior wall features the *supra-optic recess*, **recessus supraopticus** situated between the optic chiasm and the lamina terminalis and the *infundibular recess*, **recesus infundibuli** related to the in fundibulum;
- the *superior wall* made up of duplicated pia mater called the *choroid membrane of third ventricle*, **tela choroidea ventriculi tertii**. The membrane features the *choroid plexus*, **plexus choroideus** that produces the cerebrospinal fluid. Above the lamina, there is the fornix with its inferior surface attached to the outer lamina of the membrane.

Communications of the third ventricle

The third ventricle communicates with the lateral ventricles via paired *interventricular foramina*, **foramina interventricularia** situated between the columns of fornix and the thalamus. The cerebral aqueduct communicates the third ventricle with the fourth ventricle.

THE TELENCEPHALON, TELENCEPHALON

The telencephalon is the biggest compartment of the brain. It comprises the *cerebral hemispheres*, **hemispheria cerebri** separated by the *longitudinal cerebral fissure*, **fissura longitudinalis cerebri**.

Between the hemispheres and the cerebellum, one can distinguish the *transverse cerebral fissure*, **fissura transversa cerebri** that separates the two compartments. Each hemisphere features the cerebral cortex, the rhinencephalon and the *basal nuclei*, **nuclei basales**. The hemispheres are associated by means of the corpus callosum, the fornix and the anterior commissure. The telencephalon features the cavities, which are the lateral ventricles.

THE CEREBRAL HEMISPHERES, HEMISPHERIAE CEREBRI

The margins and the surfaces

Each hemisphere features the margins and the surfaces as follows:
- the *superior margin*, **margo superior** that neighbors the cranial vault;

- the *inferolateral margin*, **margo inferolateralis** directed to the internal cranial base; it is situated laterally from the inferior surface;
- the *inferomedial margin*, **margo inferomedialis** found opposite to the inferolateral margin;
- the *superolateral face*, **facies superolateralis** the largest surface adherent to the cranial vault;
- the *medial surface*, **facies medialis** that faces the opposite hemisphere;
- the *inferior surface*, **facies inferior** adherent to the internal cranial base and the cerebellum.

Relief of the cerebral cortex

Each hemisphere features the cerebral cortex that 'cloaks' the underlying compartments (Latin '**pallium**' stands for 'cloak'). On the surface of cortex, one can see numerous *cerebral sulci*, **sulci cerebri** that delimit the *cerebral lobes*, **lobi cerebri**, *cerebral lobules*, **lobuli cerebri** and the *cerebral gyri*, **gyri cerebri**.

The interlobar sulci

The deepest *interlobar sulci*, **sulci interlobares** delimit the lobes (the frontal, the parietal, the temporal and the occipital) of the cerebral hemispheres. The sulci are like the following:

- the *lateral (Sylvian) sulcus*, **sulcus lateralis (Sylvii)**, the deepest one; it arises on the inferior surface of the hemisphere as deep *lateral fossa*, **fossa lateralis** then runs superiorly and laterally to separate the temporal lobe from the frontal and the parietal lobes;
- the *central (Rolando's) sulcus*, **sulcus centralis (Rolandi)**, that crosses the superolateral face and separates the frontal and the parietal lobes;
- the *parietooccipital sulcus*, **sulcus parietooccipitalis**, the shortest interlobar sulcus situated on the medial surface of hemisphere where it separates the parietal and the occipital lobes.

The lobes of hemispheres

The lobes delimited by the interlobar sulci are like the following:

- the *frontal lobe*, **lobus frontalis**, the biggest lobe (about 30% of the entire hemisphere) situated anterior to the central sulcus. Anteriorly it terminates with the *frontal pole*, **polus frontalis**;
- the *parietal lobe*, **lobus parietalis** delimited by the central and the parietooccipital sulci;
- the *occipital lobe*, **lobus occipitalis** a small lobe delimited by the parietooccipital sulcus. Posteriorly it ends with fairly pointed *occipital pole*, **polus occipitalis**;
- the *temporal lobe*, **lobus temporalis** delimited by the lateral sulcus; inferiorly it ends with respective *temporal pole*, **polus temporalis**;
- the *insula (insular lobe)*, **insula (lobus insularis)** a small lobe situated deep within the lateral sulcus; it is fully covered by the frontal, the parietal and the temporal lobes and thus is not visible from outside.

Relief of the superolateral face of cerebral hemisphere

The superolateral face features the following sulci and gyri (Fig. 18):

The frontal lobe:

- the *precentral gyrus*, **gyrus precentralis**, delimited by the central sulcus posteriorly and the *precen-*

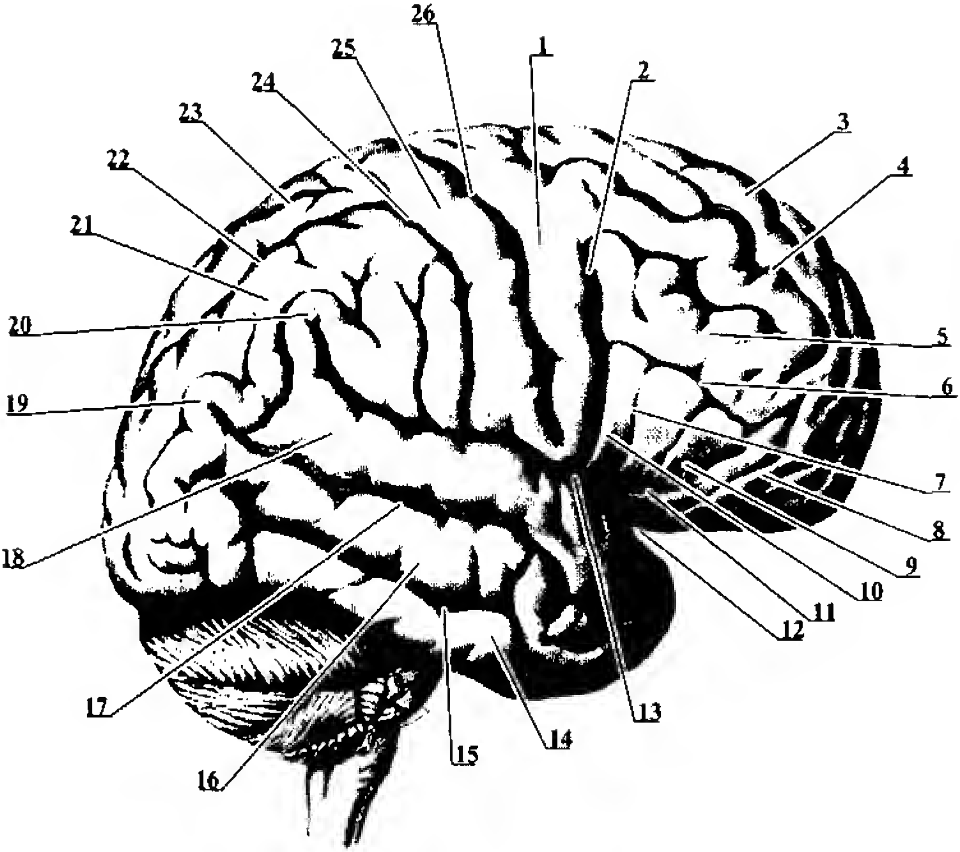

Fig. 18. The sulci and the gyri of the superolateral face of cerebral hemisphere (scheme). 1 — gyrus precentralis; 2 — sulcus precentralis; 3 — gyrus frontalis superior; 4 — sulcus frontalis superior; 5 — gyrus frontalis medius; 6 — sulcus frontalis inferior; 7 — ramus ascendens; 8 — pars orbitalis; 9 — pars triangularis; 10 — pars opercularis; 11 — ramus anterior; 12 — fossa lateralis cerebri; 13 — sulcus lateralis; 14 — gyrus temporalis inferior; 15 — sulcus temporalis inferior; 16 — gyrus temporalis medius; 17 — sulcus temporalis superior; 18 — gyrus temporalis superior; 19 — gyrus angularis; 20 — gyrus supramarginalis; 21 — lobulus parietalis inferior; 22 — sulcus intraparietalis; 23 — lobulus parietalis superior; 24 — sulcus postcentralis; 25 — gyrus postcentralis; 26 — sulcus centralis.

tral sulcus, **sulcus precentralis** anteriorly; the gyrus crosses the lobe from top to bottom;

- the *superior frontal gyrus*, **gyrus frontalis superior**, it runs longitudinally being delimited by the superior margin and the *superior frontal sulcus*, **sulcus frontalis superior**;
- the *middle frontal gyrus*, **gyrus frontalis medius** situated right below the latter. It is bounded by the superior frontal sulcus and the *inferior frontal sulcus*, **sulcus frontalis inferior**;
- the *inferior frontal gyrus*, **gyrus frontalis inferior** situated below the inferior frontal sulcus. The lateral sulcus as it reaches the inferior frontal gyrus gives off the *ascending ramus*, **ramus ascendens** and the *anterior ramus*, **ramus anterior**. These rami separate the inferior frontal gyrus into three portions:

a) the *orbital part*, **pars orbitalis** situated below the anterior ramus; it is continuous with the inferior surface of the frontal lobe;

b) the *triangular part*, **pars triangularis** situated between the two rami;

c) the *opercular part*, **pars opercularis**, situated posterior to the ascending ramus; this part covers the insula.

The parietal lobe:

- the *postcentral gyrus*, **gyrus postcentralis** delimited by the central sulcus anteriorly and the *postcentral sulcus*, **sulcus postcentralis**; the gyrus runs in the same fashion as the precentral sulcus does;
- the *superior parietal lobule*, **lobules parietalis superior** enclosed between the superior margin and the *intraparietal sulcus*, **sulcus intraparietalis**; the latter runs in the middle of the lobe parallel to the superior margin;
- the *inferior parietal lobule*, **lobulus parietalis inferior** situated below the intraparietal sulcus; the lobule features two gyri:

a) the *supramarginal gyrus*, **gyrus supramarginalis** that closes the lateral sulcus posteriorly;

b) the *angular gyrus*, **gyrus angularis** situated somewhat posterior to the latter; the gyrus closes the posterior end of the superior temporal sulcus.

The temporal lobe:

- the *superior temporal gyrus*, **gyrus temporalis superior**, situated below the lateral sulcus; inferiorly, the gyrus is delimited by the *superior temporal sulcus*, **sulcus temporalis superior**. On the internal surface of the gyrus one can see the *transverse temporal gyri*, **gyri temporales transverse** (Heshl's gyri);
- the *middle temporal gyrus*, **gyrus temporalis medius** delimited by the superior and the inferior temporal sulci;
- the *inferior temporal gyrus*, **gyrus temporalis inferior** situated below the *inferior temporal sulcus*, **sulcus temporalis inferior**.

The occipital lobe:

Here the superolateral face features small variable gyri.

The insula:

The insula is delimited from neighboring lobes by the *circular sulcus of insula*, **sulcus circularis insulae**. Here one can distinguish small *insular gyri*, **gyri insulae**.

Relief of the medial surface

On the medial surface formed by all lobes except for the insula, one can distinguish the following sulci and gyri:

- the *cingulate gyrus*, **gyrus cinguli** that encircles the corpus callosum within dimensions of the frontal and the parietal lobes. Inferiorly

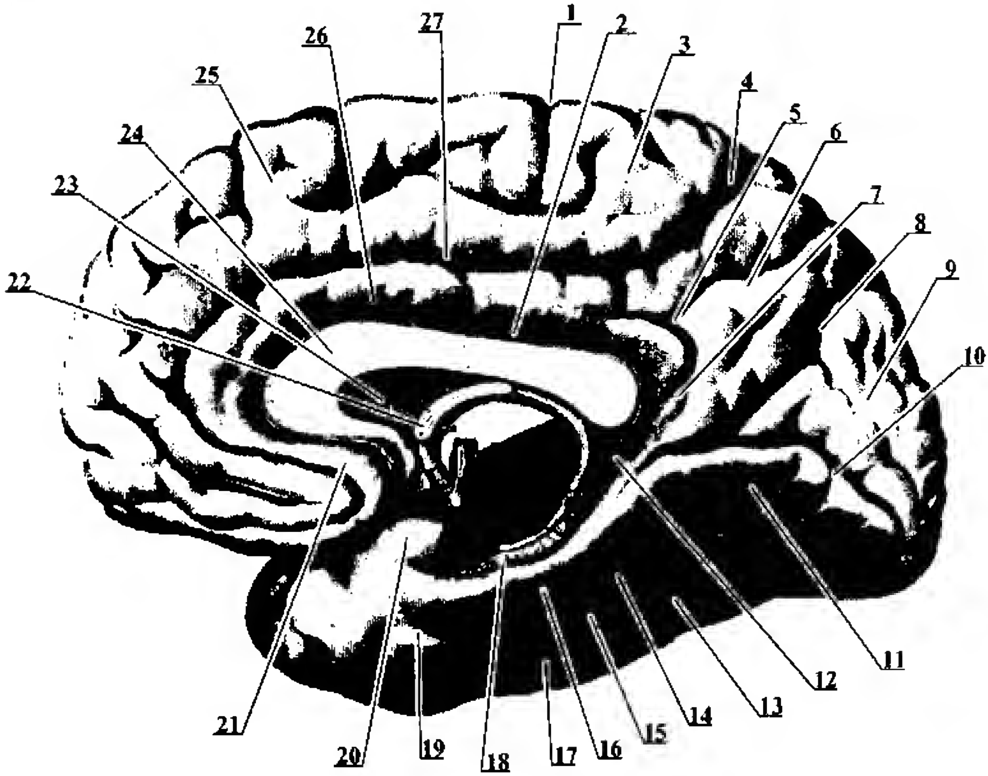

Fig. 19. The sulci and the gyri of the medial surface of cerebral hemisphere (scheme). 1 — sulcus centralis; 2 — sulcus corporis callosi; 3 — lobulus paracentralis; 4 — pars marginalis sulcus cinguli; 5 — sulcus subparietalis; 6 — precuneus; 7 — isthmus gyri cinguli; 8 — sulcus parietooccipitalis; 9 — cuneus; 10 — sulcus calcarinus; 11 — gyrus lingualis; 12 — sulcus hippocampi; 13 — gyrus occipitotemporalis lateralis; 14 — sulcus collateralis; 15 — gyrus occipitotemporalis medialis; 16 — gyrus parahippocampalis; 17 — sulcus occipitotemporalis; 18 — gyrus dentatus; 19 — sulcus rhinalis; 20 — uncus; 21 — area subcallosa; 22 — columna fornicis; 23 — lamina septi pellucidi; 24 — corpus callosum; 25 — gyrus frontalis superior; 26 — gyrus cinguli; 27 — sulcus cinguli.

it is bounded by the *sulcus of corpus callosum,* **sulcus corporis callosi** and superiorly – by the *cingulate sulcus,* **sulcus cinguli**. The gyrus eventually loops around the splenium of corpus callosum and immediately after, it narrows to form the *isthmus of cingulate gyrus,* **isthmus gyri cinguli** that in turn becomes continuous with the *parahippocampal gyrus,* **gyrus parahippocampalis**. The anterior portion of the gyrus situated below the rostrum of corpus callosum features the *subcallosal area,* **area subcallosa** covered with the paleocortex;

- the *medial frontal gyrus,* **gyrus frontalis medialis** situated above the cingulate gyrus;
- the *paracentral lobule,* **lobulus paracentralis** a small quadrangular portion of the frontal lobe situated posterior to the medial frontal gyrus. Anteriorly it is bounded by the precentral gyrus and posteriorly – by the marginal branch of cingulate sulcus (upon reaching the posterior border of the corpus callosum, the marginal branch arches upwards and reaches the superior margin of the hemisphere). Here is the area where the precentral and the postcentral gyri join;
- the *precuneus* (Lat. Id.), a bigger quadrangular area related to the parietal lobe. It features three boundaries (unlike most of the gyri and the lobules): the marginal branch of cingulate sulcus (anterior), the parietooccipital sulcus (posterior) and the *subparietal sulcus,* **sulcus subparietalis** (inferior);
- the *cuneus* (Lat. Id.), the triangular area related to the occipital lobe. It is bounded by the parietooccipital sulcus anteriorly and by the *calcarine sulcus,* **sulcus calcarinus** posteriorly as it runs slantwise to reach the occipital pole.

Relief of the inferior surface of hemisphere

The inferior surface is formed of the frontal lobe (anterior smaller portion), the temporal lobe and the occipital lobe (posterior portion). The surface features the following sulci and gyri:

The frontal lobe:

- the *straight gyrus,* **gyrus rectus** bounded by the longitudinal fissure medially and the *olfactory sulcus,* **sulcus olfactorius** (that passes the olfactory tract) laterally (Fig. 20);
- the *orbital gyri,* **gyri orbitales** that appear as some small gyri adjacent to the superior orbital wall.

The parietal and the occipital lobes:

- the *parahippocampal gyrus,* **gyrus parahippocampalis** situated on the inferomedial margin of hemisphere within dimensions of the temporal lobe. It is bounded by the *hippocampal sulcus,* **sulcus hippocampalis** with featured *dentate gyrus,* **gyrus dentatus** medially and the *rhinal sulcus,* **sulcus rhinalis** (a continuation of the collateral

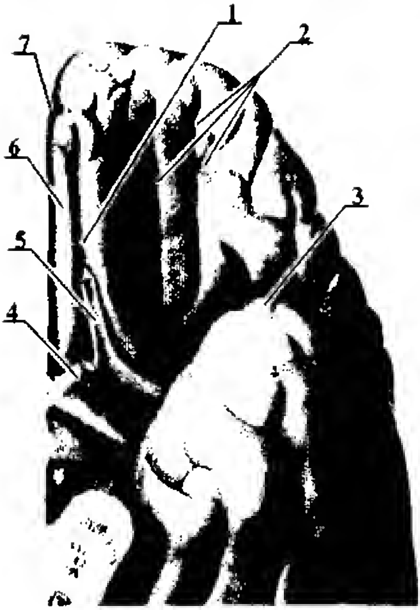

Fig. 20. The sulci and the gyri of the inferior surface of frontal lobe. 1 – sulcus olfactorius; 2 – gyri orbitales; 3 – polus temporalis; 4 – n. opticus; 5 – tractus olfactorius; 6 – gyrus rectus; 7 – fissura longitudinalis cerebri.

sulcus) laterally. Anteriorly, the parahippocampal gyrus terminates with the *uncus* (Lat. Id.). The parahippocampal gyrus and related cingulate gurus with the isthmus form the *limbic lobe*, **lobus limbicus**;

- the *lingual gyrus*, **gyrus lingualis,** the gyrus situated posterior to the isthmus of cingulate gyrus. It is bounded by the calcarine sulcus superiorly and the *collateral sulcus*, **sulcus collateralis** inferiorly; this rather deep sulcus runs along both occipital and temporal lobes to become continuous with the rhinal sulcus;
- the *medial occipitotemporal gyrus*, **gyrus occipitotemporalis medialis** bounded by the collateral sulcus and the *occipitotemporal sulcus*, **sulcus occipitotemporalis**; the latter expands between the occipital and the parietal poles;
- the *lateral occipitotemporal gyrus*, **gyrus occipitotemporalis lateralis** situated laterally from the previous and thus bounded by the occipitotemporal sulcus and the inferolateral margin of hemisphere that delimits the inferior temporal gyrus and the lateral occipitotemporal gyrus.

THE RHINENCEPHALON, RHINENCEPHALON

The rhinencephalon comprises older compartments of the hemispheres that developed with respect to the primary olfactory function of the telencephalon. In humans, the rhinencephalon is not that well developed as compared to other species and performs some more complex tasks (it is also responsible for visceral regulation, emotions and behavior) apart from olfaction itself. In the rhinencephalon, one should distinguish the peripheral and the central compartments. The peripheral compartment comprises the following portions:

- the *olfactory bulb*, **bulbus ofactorius**, an anterior extension of the olfactory tract. The bulb accepts the *olfactory nerves*, **nervi olfactorii** that arise from the nasal cavity and pass through the cribriform plate of ethmoid;
- the *olfactory tract*, **tractus olfactorius**, a bundle of neural fibers that runs along the olfactory sulcus;
- the *olfactory trigone*, **trigonum olfactorium**, a posterior triangular extension of the olfactory tract;
- the *anterior perforated substance*, **substantia perforata anterior** the posterior portion of the olfactory trigone that passes numerous blood vessels;
- the *olfactory striae (the medial and the lateral)*, **striae olfactorii (medialis et lateralis)**, the neural fibers that associate the olfactory trigone and the anterior perforated substance with the parahippocampal gyrus and the subcallosal area.

The central compartment comprises the *limbic lobe*, **lobus limbicus**, the hippocampus (the white matter projection found on the medial wall of the inferior horn of lateral ventricle), the dentate gyrus situated within the hippocampal sulcus and the subcallosal area.

THE CORPUS CALLOSUM, CORPUS CALLOSUM

The corpus callosum (also called the *greater commissure of brain*, **commissura magna cerebri**) features the commissural fibers that associate the hemispheres (Fig. 21). The portions distinguished in the corpus callosum are the trunk, the splenium, the genu and the rostrum:

- the *trunk (body)*, **truncus** is the biggest middle portion;
- the *splenium* (Lat. Id) is the posterior dilated portion of the corpus callosum;
- the *genu* (Lat. Id.) is the anterior arched portion;
- the *rostrum* (Lat. Id.) is the continuation of the genu that runs inferiorly and posteriorly. On its way to destination, it grows thinner and eventually becomes continuous with the *lamina terminalis* (Lat. Id.) that participates in formation of the anterior wall of the third ventricle.

The corpus callosum is markedly shorter than the entire hemisphere so the fibers that associate the frontal and the occipital lobes form arched *minor (anterior)* and *major (posterior) forceps*, **forceps minor (frontalis) et forceps major (occipitalis)**. These two are the portions of larger *radiation of corpus callosum*, **radiatio corporis callosi** well expressed in the middle portion; it associates the rest of the areas of cerebral cortex.

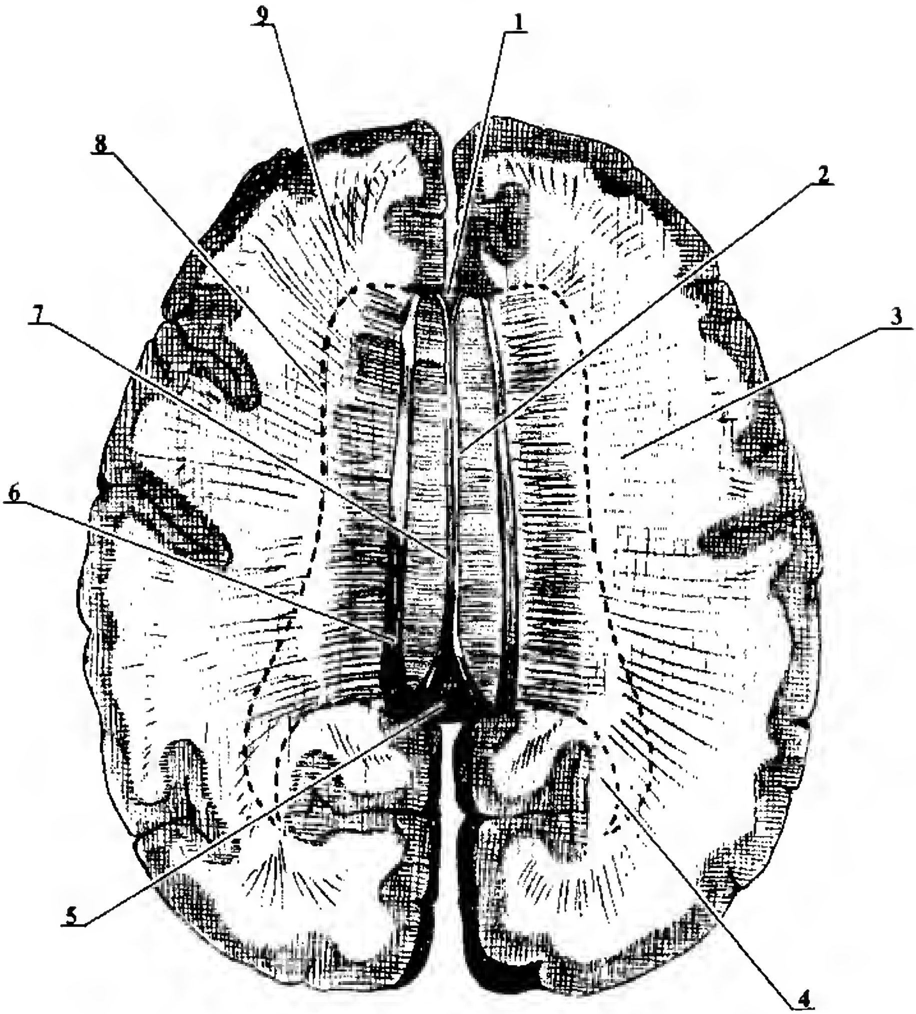

Fig. 21. The corpus callosum (horizontal section through the superior surface). 1 – genu corporis callosi; 2 – truncus corporis callosi; 3 – radiatio corporis callosi; 4 – forceps occipitalis; 5 – splenium corporis callosi; 6 – stria longitudinalis lateralis; 7 – stria longitudinalis medialis; 8 – латеральна межа бічних шлуночків; 9 – forceps frontalis.

THE ANTERIOR COMMISSURE, COMMISSURA ANTERIOR

The anterior commissure resides anterior to the columns of fornix and actually participates in formation of the anterior wall of the third ventricle. It comprises the fibers that associate the *paleocortex* areas in the frontal lobes (the olfactory triangles) and in the temporal lobes.

THE FORNIX, FORNIX

The fornix resides below the corpus callosum. It appears as two arching whitish strands that associate the mammillary bodies with the hippocampus. The fornix comprises the following portions (Fig. 22):

- the *columns*, **columnae**, the paired strands that arise from the

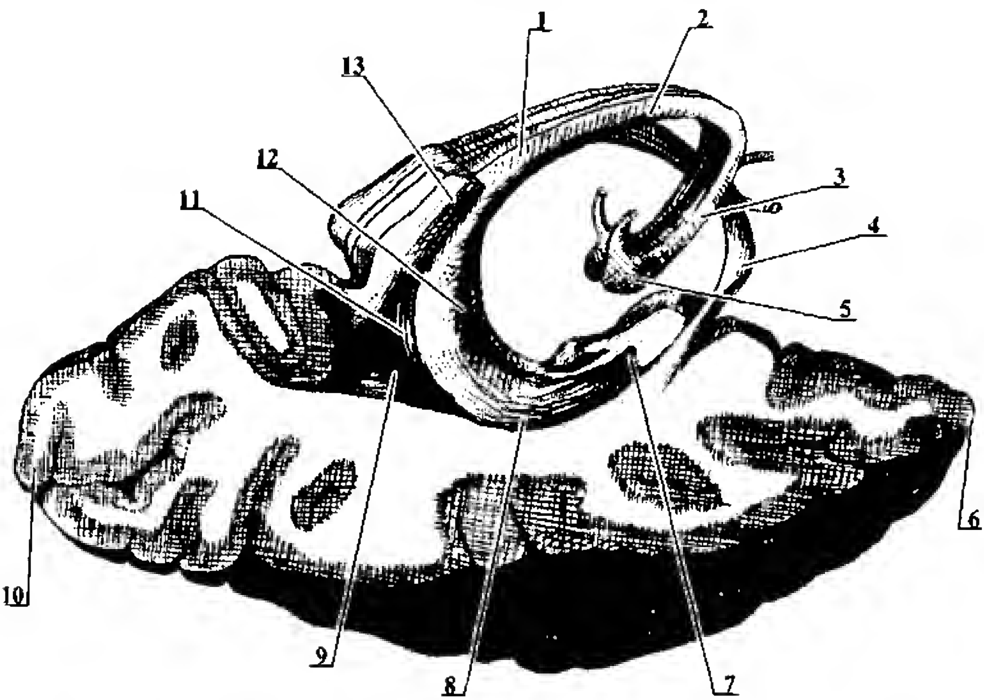

Fig. 22. The fornix, the hippocampus and the anterior commissure. 1 — crus fornicis; 2 — corpus fornicis; 3 — columna fornicis; 4 — comissura anterior; 5 — corpus mamillare; 6 — polus frontalis; 7 — pes hippocampi; 8 — hippocampus; 9 — trigonum collaterale; 10 — polus occipitalis; 11 — calcar avis; 12 — fimbria hippocampi; 13 — splenium corporis callosi.

mammillary bodies and participate in formation of the anterior wall of the third ventricle;

- the *body*, **corpus**, the middle unpaired portion situated below the corpus callosum. In this area, some fibers decussate to form the *commissure*, **commissura**;
- the *crura* (Lat. Id.), they arise from the body and proceed to the inferior horns of lateral ventricles where they become continuous with a thin *fimbria*, **fimbria hippocampi**.

The fornix contains the fibers that associate different compartments of the rhinencephalon like the hippocampus and the mammillary bodies, the mammillary bodies and the anterior thalamic nuclei, the thalamic nuclei and the amygdaloid bodies, etc.

THE SEPTUM PELLUCIDUM, SEPTUM PELLUCIDUM

The septum pellucidum appears as a thin layer of grey matter that expands between the columns of fornix and the corpus callosum. It comprises two *laminae* (Lat. Id.) that bound a slit-like cavity called *cave*, **cavum.**

THE GREY MATTER OF CEREBRAL HEMISPHERES

The grey matter of hemispheres consists of the *cerebral cortex*, **cortex cerebri**, which is relatively new and the *basal nuclei*, **nuclei basales** — the older structures. The grey matter constitutes about 40% of the entire hemisphere volume; 33% comes at the cortex and the basal nuclei take 7%.

I. The cerebral cortex, cortex cerebri

The cerebral cortex appears as 2-4 mm thick layer of the grey matter that covers the hemispheres from outside. The area of cortex is approximately 1400-1600 sq. cm. Only one third of the entire cortex area is evident on the surface of hemisphere while the rest is hidden to the sulci. The volume of cortex is about 500 cubic centimeters and the number of the neurons accounted varies from 10 to 70 billion.

The cortex features multilayer structure with six well distinguishable layers (Fig. 23):

1) the *molecular layer*, **lamina molecularis**;

2) the *external granular layer*, **lamina granularis externa**;

3) the *external pyramidal layer*, **lamina pyramidalis externa**;

4) the *internal granular layer*, **lamina granularis interna**;

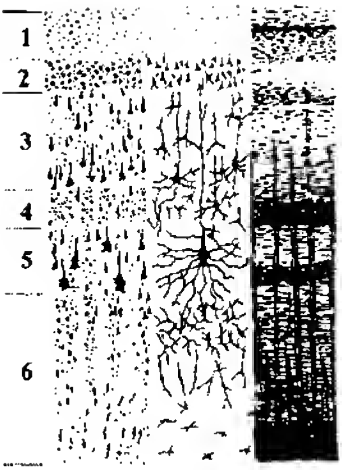

Fig. 23. Architecture of cerebral cortex. 1 — lamina molecularis; 2 — lamina granularis externa; 3 — lamina pyramidalis externa; 4 — lamina granularis interna; 5 — lamina pyramidalis interna; 6 — lamina multiformis. A — шари клітин; B — типи клітин; C — шари волокон.

5) the *internal pyramidal layer*, **lamina pyramidalis interna**;

6) the *multiform layer*, **lamina multiformis**.

Architectonics of cerebral cortex V.A. Betz's researches

Although six-layer arrangement persists in most of the areas of cerebral cortex, the featured layers reveal local variability in thickness and cellular contents. A study of local features of cortex structure is called architectonics of cerebral cortex. The architectonics in turn is subdivided into cytoarchitecture, which studies local features of cellular contents and myeloarchitecture, which deals with related nerve fibers.

The study of the cortex architecture was founded and developed by Kiev anatomist V.A. Betz, who was the first to distinguish the areas depending on cellular contents. He provided histological description of several cortical areas and discovered gigantic pyramidal cells (1874) named after him.

In 1890, V.A. Betz issued atlas of cortical architecture.

Numerous studies of the cortex architecture allowed compilation of cytoarchitectural and myeloarchitectural charts with the numbers assigned to each specific area. According to Brain institute (Moscow) data, the cortex features 52 areas.

From the evolutional point of view, the cortex features certain structural heterogeneity. Most part of it is represented with the *neocortex* (over 95.6%).

The hippocampus, the dentate gyrus and the uncus feature the *archicortex* related to the rhinencephalon. Small areas of the olfactory bulb and the olfactory trigone feature the *paleocortex*.

The paleocortex and the archicortex are primitive as compared to the neocortex and have two to three layers distinguishable.

II. The basal nuclei, nuclei basales

The basal nuclei appear as considerable aggregations of grey matter situated within the hemispheres next to inferior (basal) surface. They are represented with the corpus striatum,

the claustrum and the amygdaloid body (Fig. 24).

1) The *corpus striatum* (Lat. Id.) comprises two big nuclei — the caudate nucleus and the lentiform nucleus.

The *caudate nucleus*, **nucleus caudatus** resides anteriorly and laterally from the thalamus. It has the head, the body and the tail:

- the *head*, **caput** is the anterior thicker portion;
- the *body*, **corpus** is the middle portion;
- the *tail*, **cauda** is the posterior narrower portion.

The caudate nucleus arches so that the head appears as the lowermost part that reaches the anterior

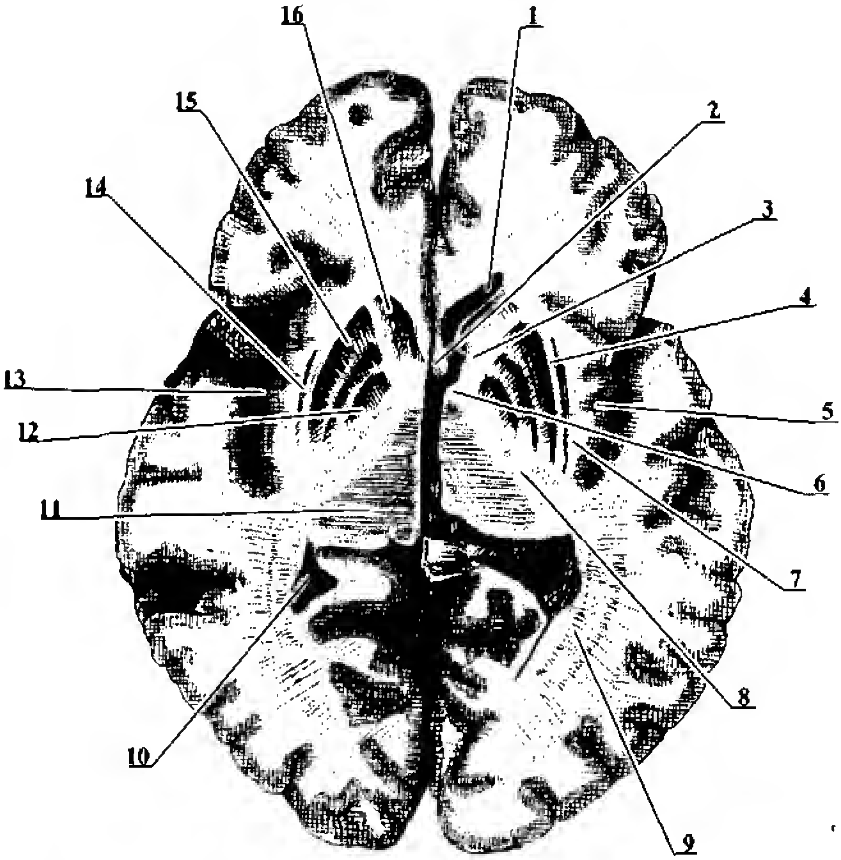

Fig. 24. Horizontal section of cerebral hemispheres. 1 — cornu frontale ventriculi lateralis; 2 — columna fornicis; 3 — crus anterius capsulae internae; 4 — capsula externa; 5 — insula; 6 — genu capsulae internae; 7 — capsula extrema; 8 — crus posterius capsulae internae; 9 — radiatio optica; 10 — cornu occipitale ventriculi lateralis; 11 — thalamus; 12 — globus pallidus; 13 — fissura lateralis; 14 — claustrum; 15 — putamen; 16 — caput nuclei caudati.

perforated area. Most part of it occupies the lateral wall of lateral ventricle. The body neighbors the thalamus and thus forms the floor of the central part of lateral ventricle. The tail runs along the superior wall of the inferior horn of lateral ventricle to reach the amygdaloid body.

The *lentiform nucleus*, **nucleus lentiformis** resides laterally from the thalamus and caudate nucleus being delimited by the internal capsule. Sectioned nucleus appears as triangular area with the base directed to the insula and the apex directed to the thalamus. The nucleus comprises two parts: the *putamen* (Lat. Id), which is the larger, darker outmost portion, and the *globus pallidus* (Lat. Id.) – the inner, lighter, paired segments.

The striopallidary system

The caudate nucleus and the putamen are associated by means of grey and white matter stria, which give that striated look to the sectioned nuclei. Both are relatively new as compared to the globus pallidus and feature similar structure and functions. They are known as the **neostriatum (striatum)**.

The globus pallidus in turn is the older structure and thus belongs to the **paleostriatum (pallidum)**. Clinical specialists refer to this complex as the striopallidary system.

The nuclei of the corpus striatum as the superior centers of the extrapyramidal system

In the inferior animals, who lack the cerebral cortex these nuclei serve as principal motor centers responsible for complex automated movements (swimming, running, jumping etc.). The cortex as it evolves does not fully eliminate significance of the nuclei that continue with muscle tonus maintenance, coordination of automated movements, creation of emotions and responsibility for individual features of the movements.

Association centers of the cortex of frontal lobe are closely connected to the corpus striatum and the claustrum (the striatum). From the striatum, the pathway proceeds to the pallidum, from the pallidum – to the thalamus and further to the motor areas of the cerebral cortex. The nuclei employ the pathways for participation in programming of the complex automated movements.

Injury to the nuclei result in various motor disorders like tremor in arms, labored movements (parkinsonism), involuntary forced movements, tonus disorders etc.

2) The *claustrum* (Lat. Id.) is a thin layer of grey matter that resides laterally from the lentiform nucleus. The boundary between them appears as thin layer of white matter called the *external capsule*, **capsula externa**. Another white matter layer – the *extreme capsule*, **capsula extrema** – separates the claustrum from the insula.

3) The *amygdaloid body*, **corpus amygdaloideum** resides within the temporal lobe anterior to the inferior horn of lateral ventricle. It is one of the principal centers of the limbic system, which communicates with the hypothalamus and the olfactory centers.

THE WHITE MATTER OF CEREBRAL HEMISPHERES

The white matter appears as quite a thick layer between the cerebral cortex and the basal nuclei. It consists of nerve fibers arranged into three systems – the association, the commissural and the projection pathways.

Association fibers (Fig. 25) connect *different* areas within *the same* hemisphere. They are subdivided into the long and the short fibers:

1) the *short association fibers* represented with a single type of fibers called the *arcuate fibers*, **fibrae arcuatae cerebri** associate the neighboring gyri;

2) the *long association fibers* associate the lobes instead; the fibers distinguishable are as follows:

- the *superior longitudinal fasciculus*, **fasciculus longitudinalis superior**, it runs above the corpus callosum to associate the frontal lobe with the parietal and the occipital lobes;
- the *inferior longitudinal fasciculus*, **fasciculus longitudinalis inferior,** it associates the temporal and the occipital lobes;
- the *cingulum* (Lat. Id.), a bundle of fibers confined to the cingulate

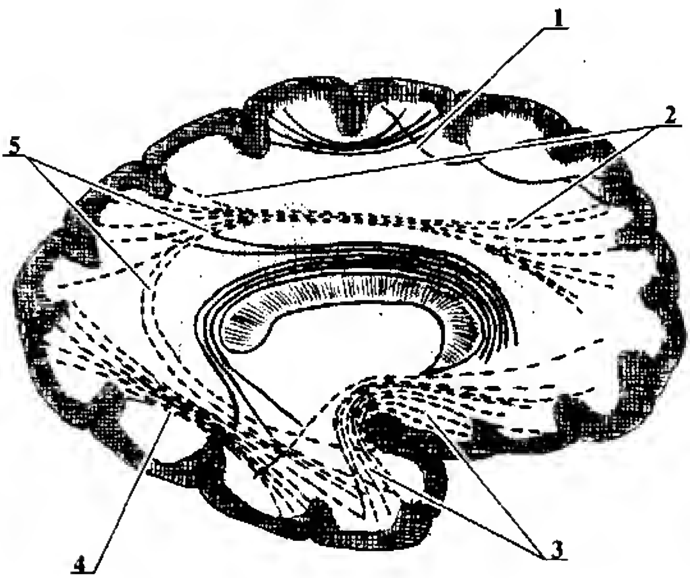

Fig. 25. Association fibers of cerebral white matter. 1 – fibrae arcuatae cerebri; 2 – fasciculus longitudinalis superior; 3 – fasciculus uncinatus; 4 – fasciculus longitudinalis inferior; 5 – cingulum.

gyrus; it associates the frontal, parietal and the temporal lobes;
- the *uncinate fasciculus*, **fasciculus uncinatus**, it arises in the temporal and the parietal lobes and terminates within the inferior frontal gyrus; on its way to destination the fasciculus rounds the lateral sulcus.

The *commissural fibers* associate *identical* areas in *different* hemispheres. Most of the commissural fibers belong to the corpus callosum, yet some other run within the anterior commissure and the commissure of fornix.

The *projection fibers* associate the cerebral cortex with underlying nuclei both of the brainstem and the spinal cord. The fibers arise or terminate in certain areas of the cerebral cortex as if they project onto it.

The projection fibers compacted within the internal capsule part as they leave it and radiate to form the *corona radiata* (Lat. Id.) that eventually reaches the cerebral cortex.

THE INTERNAL CAPSULE, CAPSULA INTERNA

The internal capsule appears as quite a thick layer of white matter found between the lentiform nucleus on one side and the thalamus with the head of caudate nucleus on the other. Horizontal sections of the hemispheres reveal it as arched plate with two limbs and genu distinguishable:
- the *anterior limb*, **crus anterius** resides between the head of the caudate nucleus and the lentiform nucleus; here, the descending pathways that associate the frontal lobe with the thalamus and the pons pass;
- the *genu of internal capsule*, **genu capsulae internae** that passes the *corticonuclear fibers*, **fibrae corticonucleares** (they are the pyramidal fibers);
- the *posterior limb*, **crus posterius** situated between the lentiform nucleus and the thalamus; its anterior portion passes the descending *corticospinal fibers*, **fibrae corticospinales** (also the pyramidal fibers). Posterior to the corticospinal fibers one can distinguish the ascending *thalamocortical fibers*, **fibrae thalamocorticales** that transmit exteroceptive and proprioceptive impulses. The posterior portion of the internal capsule contains the auditory and the visual fibers continuous with the *acoustic radiation*, **radiatio acoustica** and the *optic radiation*, **radiatio optica**, the fan-shaped bundles that reach the temporal and the occipital lobes respectively.

Clinical applications

As far as the projection pathways are compacted within the internal capsule, the hemorrhages result in severe damage of the bundles. The pyramidal fibers are most commonly

affected and it results in paralysis of the muscles on the contralateral side. Injury to the posterior limb results in exteroceptive and proprioceptive sensitivity loss and in visual and auditory disorders.

THE LATERAL VENTRICLES, VENTRICULI LATERALES

The lateral ventricles are the largest cavities of the cerebral hemispheres. The ventricles are the left and the right (the first and the second respectively). Each ventricle comprises the central part, the anterior the posterior and the inferior horns:

- The *anterior horn*, **cornu anterius** is the portion situated within the frontal lobe (and thus it is also called the *frontal horn*, **cornu frontale**); its lateral and inferior walls are formed by the head of caudate nucleus, the medial wall – by the septum pellucidum, the anterior wall – by the genu of the corpus callosum and the superior wall – by the trunk of corpus callosum.
- The *central part*, **pars centralis** resides within the parietal lobe. Its superior wall is formed of the corpus callosum and the inferior wall – by the thalamus, the body of caudate nucleus and the *stria terminalis* (Lat. Id.). Medially, one can distinguish the body of fornix and the *choroidal fissure*, **fissura choroidea** below it; the fissure passes the *choroid plexus*, **plexus choroideus**.
- The *posterior horn*, **cornu posterius** is embedded into the white matter of the occipital lobe. Superiorly it is covered by the corpus callosum fibers. Its medial wall features two eminences: the calcarine spur and the bulb of occipital horn:

  - the *calcarine spur*, **calcar avis** is the lower eminence left by the calcarine sulcus;
  - the *bulb of posterior horn*, **bulbus cornu posterioris** resides superiorly and anteriorly from the calcarine spur. This eminence is left by the parietooccipital sulcus.

  The inferior wall of the posterior horn features the *collateral trigone*, **trigonum colaterale** left by the *collateral sulcus*, **sulcus collateralis**.
- The *inferior horn*, **cornu inferius** resides within the temporal lobe. Its walls are mostly formed of the white matter of the lobe yet the medial portion of the upper wall contains the tail of caudate nucleus. On the medial wall of horn, one can distinguish a thick arched projection called the *hippocampus* (Lat. Id.). Inferiorly it terminates with the *pes*, **pes hippocampi** with several projections called the *hippocampal digitations*, **digitationes hippocampi**. Medial surface of the hippocampus fuses with the *fim-*

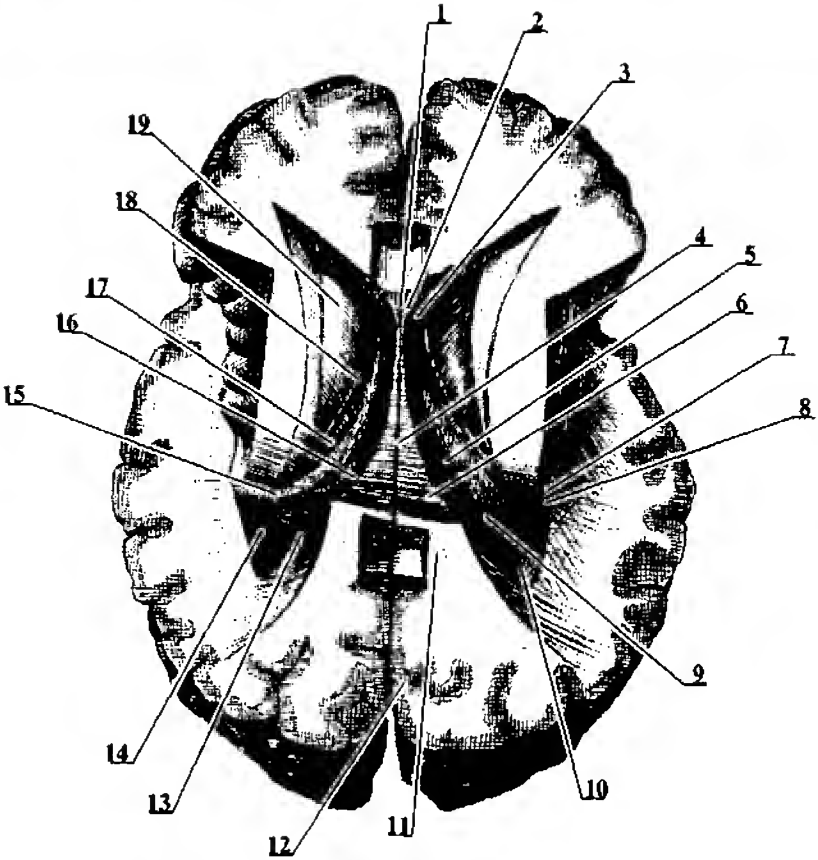

Fig. 26. The lateral ventricles (superior view). 1 — cavum septi pellucidi; 2 — lamina septi pellucidi; 3 — cornu frontale; 4 — corpus fornicis; 5 — fimbria hippocampi; 6 — crus fornicis; 7 — eminentia collateralis; 8 — cornu temporale; 9 — hippocampus; 10 — cornu occipitale; 11 — corpus callosum; 12 — sulcus calcarinus; 13 — calcar avis; 14 — trigonum collaterale; 15 — plexus choroideus ventriculi lateralis; 16 — fissura choroidea; 17 — thalamus; 18 — stria terminalis; 19 — caput nuclei caudati.

bria, **fimbria hippocampi**, which arises from the crus of fornix. The medial wall features the choroid plexus that descends from the central part and adheres to the hippocampal fimbria. Inferior wall of the horn features the *collateral eminence*, **eminentia collateralis** that continues here from the collateral trigone of the posterior horn. It is also left by the collateral sulcus.

The *choroid plexus of lateral ventricle*, **plexus choroideus ventriculi lateralis** is the part of pia mater duplication that enters the lateral ventricle via the *choroidal fissure*. The

choroid plexus resides in the central part and in the inferior horn of the lateral ventricle. It features vascular plexus lined with villous epithelium that possesses dense capillary network. The villi are responsible for production of the cerebrospinal fluid that fills all cavities and the subarachnoidal space. As the choroid plexus of lateral ventricle reaches the interventricular foramen, it becomes continuous with the choroid plexus of the third ventricle.

The *interventricular foramen*, **foramen interventriculare** is the opening found between the columns of fornix and the thalamus. The foramen connects the lateral ventricles to the third ventricle and passes the choroid plexus.

FUNCTIONAL ARRANGEMENT OF THE CEREBRAL CORTEX

By present, the cerebral cortex is the highest yield of CNS evolution. It is well distinguishable in mammals only and reaches its maximum development in primates especially in humans.

History of functional studies

Functional studies begin their history from the works of Austrian physician F. Gall (1758-1828) who created phrenology — "a study of human spiritual abilities". F. Gall believed that all functions of the brain even the superior qualities like memory, will etc. are confined to allocated areas with exact limits. He also believed that the developing areas have an effect on skull shape allowing thus making some suggestions on individual's character simply by palpation of head.

Another theory advanced by M. Florence in 1830 suggested equipotence (equivalence) of the cortical areas. It was based on experimental cortex removal in birds (pigeons).

In 1864, French scientist P. Broca proved that injury to a certain area of cortex leads to motor speech disorders.

In 1870, German scientists G. Fritsch and E. Hitzig performed intraoperative stimulation of cerebral cortex in humans. They noticed that stimulation of the precentral gyrus eventually leads to muscle contractions on the opposite side.

In 1874, German psychiatrist C. Wernicke described speech disorders after injury to the temporal lobe.

Further studies proved that the cerebral cortex features function-specific areas and regular structure. These studies were started by V.A. Betz in 1874.

I.P. Pavlov considered the cerebral cortex as continuous perceiving area or a set of cortical ends of analyzers. The term 'analyzer' stands for complex neural mechanism that comprises receptor apparatus, the pathways

and the cortical center responsible for analysis of all incoming data. I.P. Pavlov proved that the cortical end of analyzer is not confined to a certain area but features the nucleus and the dissipated elements. The nucleus performs the superior functions like analysis and synthesis. The nucleus has well distinguishable limits whilst the dissipated elements may reside close to the nucleus periphery or quite away from it. The dissipated elements perform the same functions as the nucleus yet their tasks are simpler. In the case of damage to the nucleus, the dissipated elements may partially restore activities of the cortical end. The dissipated elements have no distinct limits and very often, the neighboring zones overlap.

Modern clinical, anatomical and experimental researches allow mapping the most specialized areas of the cerebral cortex – the somatosensory, the visual, the auditory and the motor areas. Basing on the data obtained, the researches made fundamental conclusions on sensory and motor areas that appear as two-dimensional maps that mirror the respective body areas. The maps are subject to a common rule: the area of the respective cortical zone depends on sensitivity level or movement precision degree.

THE SENSORY ZONES OF CERBRAL CORTEX

The primary sensory centers

The primary sensory centers accept the fibers that arise from the thalamic nuclei including the lateral and the medial geniculate bodies. These centers feature well distinguishable projection areas related to respective sensory pathways.

The *somatosensory cortex* occupies the postcentral gyrus, where the thalamocortical fibers terminate (they arise from the ventrolateral nucleus of the dorsal thalamus). The gyrus contains the centers of skin sensitivity (pain, temperature and tactile) and proprioceptive sensitivity. The upper portion of the gyrus is responsible for the lower limbs and the trunk, the middle portion – for the upper limb and the lower portion – for the head and the neck. The body thus is mirrored in 'upside down' fashion; the largest areas are related to the head and the hands. As far as the afferent fibers decussate on various levels, the right hemisphere deals with the left half of the body and vice versa.

The *visual cortex* occupies the marginal areas of the calcarine sulcus (of the occipital lobe). It accepts the fibers that arise from the visual relay nuclei located in the lateral geniculate body and the pulvinar of thalamus. The left half of each visual area is represented in the right hemisphere and vice versa.

The *auditory cortex* occupies the transverse temporal gyri (Heshl's gyri) that reside on the internal surface of the superior temporal gyrus that faces the insula. The fibers that arise from the auditory relay nuclei situated within the medial geniculate bodies and the inferior colliculi of the tectal plate eventually terminate within this area. Each area accepts both contralateral and ipsilateral fibers.

The *olfactory cortex* occupies the uncus of the parahippocampal gyrus. It accepts the fibers from ipsilateral olfactory bulb and the subcortical centers. The olfactory system is a single unit with the fibers that bypass the thalamic nuclei on the way to destination point. The olfactory cortex is also responsible for analysis of gustatory impulses.

Association sensory areas

The association areas reside between the primary sensory areas related to the occipital, parietal and the temporal lobes. These areas perform advanced data processing and occupy larger areas.

Experimental studies demonstrated that the primary sensory areas are not true cortical ends of analyzers. They perform primary data processing and submit the results to the association areas. The association areas feature wide communications with the hypothalamus, the hippocampus, the amygdaloid bodies and the thalamus so the data processed acquire emotional tints. The association areas are solely responsible for creation images and formation of complex full-shaped feelings.

The association areas transmit the impulses to the efferent cortex (of the frontal lobe), which is responsible for the actions.

The efferent (motor) areas

The motor centers occupy the postcentral gyrus and the paracentral lobule. The upper portions of the gyrus and the lobule are responsible for the muscles of the lower limbs and the trunk, the middle portions — for the muscles of upper limbs and the lower portions — for the muscles of the head and the neck. The skeletal muscles thus are represented in the same fashion as the sensory areas. The largest areas of the motor cortex deal with the muscles of hand, the mimic muscles and the muscles of tongue.

The gigantic pyramidal cells situated in the fifth layer of the postcentral gyrus give rise to the pyramidal tracts (the corticospinal and the corticonuclear tracts). As far as the fibers decussate at certain levels, the right motor areas control the left half of the body and vice versa. The motor cortex controls accuracy of voluntary movements.

The association areas occupy the most part of the frontal lobe anterior to the precentral. They communicate with the thalamic nuclei, the nuclei of corpus striatum and with the cerebellum. Apart from this, the frontal lobe accepts the impulses from the association areas of the occipital, parietal and the temporal lobes. The intermediate

zone features the centers responsible for the movements of eyes and head and the inferior portion of the frontal lobe features the speech motor centers. The association areas of the frontal lobe control the individual's behavior. The impulses from the frontal lobe proceed to the precentral gyrus, which in turn gives rise to the motor pathways to the executive centers.

Speech centers

The speech function appears to be relatively new in evolution course, so the speech functions are not well localized. Speech centers development is anatomically predisposed yet at early stages of embryo's existence but adequate functioning requires quite a long training. That is why the speech centers become apparent after birth and occupy only one hemisphere (as a rule the right-handed ones feature the speech centers in the left hemisphere and vice versa).

The entire speech system features the sensory and the motor centers. The sensory centers reside in the posterior speech area. They deal with perception of auditory signals (conversational responsibility) and the visual signals (reading responsibility). The motor centers generate speech response in the form of words pronunciation (articulation responsibility) and character spelling (graphics responsibility). These centers occupy the posterior speech area of the frontal lobe.

The posterior speech area

This area resides at the point where the parietal, the temporal and the occipital lobes join. It is associated with the primary auditory and visual cortex. The impulses generated from the auditory perception first reach the primary auditory cortex and eventually reach the posterior portion of the *superior temporal gyrus* and the *supramarginal gyrus* i.e. to the auditory speech center[1]. Data processing in this area is required for comprehension.

The impulses from the visual perception reach the primary visual cortex (the marginal area of the calcarine sulcus) and terminate within the angular gyrus, which features the visual speech center. This center deals with characters recognition.

The visual and the auditory speech centers maintain tight association because comprehension of the words written requires conversion of the images into sound shell, which is under responsibility of the Wernicke's area.

The **anterior speech area** resides in the frontal lobe namely within the *triangular part* of the inferior frontal gyrus. This area contains the motor speech center. This center programs speech articulation and sends the impulses to the inferior portion of the precentral gyrus that features the motor centers for the laryngeal muscles, the muscles of tongue and the mimic muscles.

The pre-motor area of the middle frontal gyrus, which occupies

[1] — the Wernicke's area

its posterior portion, contains the writing motor center (the Broca's area). This center programs precise movements of the upper limb required for words spelling. The data encoded is transmitted to the middle portion of the precentral gyrus, which controls the muscles of upper limb.

Association of the sensory and the motor areas

The speech areas maintain communication via the uncinate fasciculus and always act together. According to modern concept, the phrase structure is gener in the posterior speech area (in the Wernicke's area) and proceeds to the Broca's area via the uncinate fasciculus to trigger the speech articulation program. Injury to the Broca's area results (depending on injury severity) either in complete inability to produce articulate speech or in partial disorders seen as slow labored speech with pronounced articulation impairments and grammar errors. The condition yet features preserved comprehension. Injury to the Wernicke's area results in severe speech disorders manifested as both language comprehension and language production inability. Injury to the uncinate fasciculus results in accelerated and well-articulated yet rather meaningless speech. This occurs because the motor area receives no impulses from the Wernicke' area. Comprehension is not impaired as well because the Wernicke's area remains intact.

Functional asymmetry of the hemispheres

As far as the speech centers reside only in the left hemisphere (in 95% of occurrences), it is called the speech or the dominant hemisphere. The hemispheres thus appear to be functionally unequal. In recent years, the modern treatment techniques (shock therapy, commissurotomy, endarterial anesthesia, etc.) allowed dedicated functional studies of a single cerebral hemisphere. The left hemisphere with featured speech centers is believed to be responsible for abstract thinking characteristic of the humans only. The right hemisphere on the contrary deals with concrete thinking. Disconnection of the right hemisphere results in marked speech fluency and wordiness accompanied by unmotivated good humor yet speech lacks intonation and voice changes considerably. Ability to perceive the word also appears to be impaired. Perception of non-speech sounds (noise, rain, and animals' voices) undergoes harsh impairment as well.

Exclusion of the left hemisphere leads to impaired ability to comprehend any sort of speech and to produce speech. Perception of non-speech sounds on the contrary seems to be better than in normal individuals. The state is characterized by low mood.

From the evolutional point of view, the functions of the left hemisphere are much newer than those of the right hemisphere are and therein lies principal distinction between the humans and the animals.

THE LIMBIC SYSTEM

Components of the limbic system

The limbic system (otherwise called the visceral brain or the rhinencephalon) comprises the structures that occupy the medial surface of the hemisphere and neighbor the corpus callosum and the diencephalon (Latin '**limbus**' stands for '**margin**'). First of all, they are the components of the rhinencephalon – the cingulate gyrus, the parahippocampal gyrus, the dentate gyrus, the uncus, etc. The limbic system also comprises the amygdaloid bodies, the hippocampus, the septum pellucidum, the mammillary bodies, the fornix, the thalamus and the hypothalamus. This vast complex regulates viscera activities and homeostasis.

Functions of the limbic system

Stimulation to the pertaining nuclei exerts various effects on blood circulation, respiration, digestion, urination and sexuality. Apart from this, emotional status of the individual also changes. Modulation of the nuclei activities results in variety of emotional affects that range from relief, pleasure, joy and satisfaction to fear, anxiety and horror.

Associations of the limbic system

The principal components of the limbic system are the hippocampus and the amygdaloid bodies, which both maintain associations with the hypothalamus. Apart from this, they appear to be the destination point for the impulses that arise from numerous areas of the neocortex. Because of these vast associations the separate emotional reactions group into single affect subordinate to cortical activities. Impulses generated by the limbic system provide emotional tints to any response (e.g. of speech or motion) sent to environment.

THE NEURAL PATHWAYS

The neural pathways are the special interrupted association lines. They are formed by the neurons that give off the bundles of fibers that transmit the impulses from periphery (various types of receptors) to the CNS and in opposite direction i.e. from the brain and spinal cord down to the effectors. The relay points (the nuclei) are the data processing nodes. These data processing units recode the input data otherwise the raw data is likely to be misinterpreted by the superior parser units (the cortical analyzers). The pathways are subdivided into afferent or sensory (ascending) pathways and efferent or motor (descending) pathways.

THE AFFERENT PATHWAYS

The *proprioceptive pathways* (the *pathways of deep sensitivity*) transmit the signals from the muscles, the fascia, the joints and the periosteum i.e. from the locomotor apparatus. The pertaining organs feature the proprioceptors that accept the specific stimuli and generate response for the CNS. This system provides spatial sensation of body posture and muscle tonus sensation. Proprioceptive sensitivity is prerequisite for movements' coordination because it provides data on posture alterations as it employs the loopback principle. The proprioceptive pathways are subdivided into: 1) the pathways to the cerebral cortex and 2) the pathways to the cerebellum.

1. The proprioceptive pathways to the cerebral covtex

The *first neurons* reside in the spinal and the cranial ganglia. They are the sensory pseudounipolar cells with featured central and peripheral processes. The peripheral processes (identical to dendrites in the multipolar cells) run within the spinal and the cranial nerves and terminate with the receptors that accept stimuli from the muscles, the tendons, the periosteum and the joints. The central processes (identical to axons in the multipolar cells) form the posterior roots of the spinal cord or the sensory roots of the cranial nerves and thus enter the spinal cord or the brainstem.

In the spinal cord, the fibers run directly to the posterior funiculi to form the *cuneate* and the *gracile fasciculi.*

The *gracile fasciculus* (Goll's tract) carries the impulses from the lower limbs and the lower portion of the body; it is well distinguishable all along the spinal cord.

The *cuneate fasciculus* (Burdach's tract) carries the impulses from the upper portion of the body, the upper limbs and the neck. It is evident beginning from Th4 and up. The cuneate and the gracile fasciculi reach the medulla oblongata to synapse with the neurons of the *gracile* and the *cuneate nuclei.*

The *second neurons* of the chain thus reside within the aforesaid nuclei. They give off the *external arcuate fibers* and the *internal arcuate fibers.* The external arcuate fibers run directly to the cerebellum (they constitute the indirect proprioceptive tract to the cerebellum) whilst the internal arcuate fibers decussate and form the medial lemniscus that runs through the dorsal portion of the medulla oblongata the tegmentum of pons, the tegmentum of cerebral peduncle and eventually reaches the ventrolateral nucleus of the dorsal thalamus.

The cranial proprioceptive pathways interrupt within the respective sensory nuclei; their fibers also decussate and join the medial lemniscus.

The *third neurons* of the chain reside within the ventrolateral nucleus of the

thalamus (on each side). Their axons ascend and pass through the posterior limb of the internal capsule, join the corona radiata and terminate within the cortex of the postcentral gyrus.

As the result of fibers decussation, the right half of the body is associated with the left postcentral gyrus and vice versa.

2. The proprioceptive pathways to the cerebellum

The cerebellum-related pathways run within the spinal cord as two tracts – the anterior and the posterior spinocerebellar tracts. They reside in the lateral funiculus of the spinal cord.

The *anterior (ventral) spinocerebellar tract*, **tractus spinocerbellaris anterior (ventralis)** (Gowers' tract)

The *first neurons* of the chain reside within the spinal ganglia (it is a common rule for spinal tracts). The central processes of these sensory pseudounipolar cells form the posterior roots of the spinal cord and reach the grey matter to synapse with the cells of the *intermediomedial nucleus*.

The axons of the *second neurons* (of the *intermediomedial nucleus*) form incomplete decussation and reach the lateral funiculus to form the anterior spinocerebellar tract. The latter ascends to traverse the medulla oblongata and the pons and reaches the superior medullary velum. Upon entering the velum the fibers decussate again and turn back to enter the superior cerebellar peduncle. The fibers terminate in the cortex of vermis (the *paleocerebellum*).

The *posterior (dorsal) spinocerebellar tract*, **tractus spinocerbellaris posterior (dorsalis)** (Flechsig's tract)

The *first neurons* of the chain reside in the spinal ganglia. The axons of the sensory pseudounipolar cells form the posterior roots and enter the spinal cord via the dorsolateral sulcus. In the spinal cord, they synapse with the cells of the *thoracic nucleus*, which are the second neurons.

The axons of the *second neurons* do not decussate and proceed to the lateral funiculus on the same side where they form the posterior spinocerebellar tract. The latter reaches the medulla oblongata and enters the cerebellum via the inferior cerebellar peduncles. These fibers also terminate within the cortex of the vermis (the *paleocerebellum*).

3. The exteroceptive pathways

The exteroceptive pathways transmit the impulses from the skin receptors (skin sensitivity), the retina (the visual sensitivity), the internal ear (auditory sensitivity) and the tongue papilla (taste sensitivity).

The pathways for pain and temperature sensitivity

Pain and temperature impulses from the skin of the trunk, the neck and partially from the head and both upper extremities are transmitted via the *lateral spinothalamic tract*, **tractus spinothalamicus lateralis**.

The *first neurons* of the chain reside within the spinal ganglia. The peripheral processes of these sensory pseudounipolar cells run to the skin receptors that accept the stimuli. The central processes form the posterior roots and enter the spinal cord via the dorsolateral sulcus.

The *second neurons* reside in the *nucleus proprius* (of the posterior grey column). The axons of the pertaining cells decussate and enter the lateral funiculus to form the *lateral spinothalamic tract*, **tractus spinothalamicus lateralis**. The tract runs medially from the anterior spinocerebellar tract; it also traverses the medulla oblongata, the tegmentum of pons the tegmentum of cerebral peduncle and reaches the ventrolateral nucleus of thalamus to synapse with the featured cells.

The axons of the *third neurons* (of the ventrolateral nucleus of thalamus) join the thalamo-cortical bundles that pass through the posterior limb of internal capsule, join the corona radiata and eventually terminate in the poscentral gyrus.

The pain and temperature pathways from facial skin, nasal and oral mucosa, the teeth and the tongue

These fibers belong to the trigeminal nerve. The *first neurons* reside within the trigeminal ganglion.

The *second neurons* reside within the *spinal nucleus of trigeminal nerve*. The axons of the cells featured decussate and join the lateral spinothalamic tract to reach the thalamus (the ventrolateral nucleus that comprises the third neurons). The axons of the *third neurons* pass through the posterior limb of internal capsule and reach the inferior portion of the postcentral gyrus.

The pathways for tactile sensitivity

The tactile (sense of touch and pressure) sensitivity impulses from the skin of the trunk and the neck and partially from the skin of the head and both upper limbs are transmitted by the *cuneate* and *gracile fasciculi* and by the *anterior spinothalamic tract*, **tractus spinothalamicus anterior**.

The *anterior spinothalamic tract*, **tractus spinothalamicus anterior**

The *first neurons* are the sensory pseudounipolar cells of the spinal ganglia. The central processes of the cells enter the spinal cord to take two different routes. Some fibers proceed to the posterior funiculus directly whilst the rest reaches the posterior grey column that contains the second neurons.

The *second neurons* of the chain occupy the dorsal periphery of the posterior grey column (the *gelatinous substance*). The axons of the second neurons decussate and enter the anterior funiculus to form the *anterior spinothalamic tract*. The tract ascends to the medulla oblongata and joins the medial lemniscus.

The *third neurons* reside within the ventrolateral nucleus of thalamus. Their axons join the thalamo-cortical fibers and reach the postcentral gyrus.

The tactile sensitivity from facial skin, nasal and oral mucosa, the teeth and the tongue is under responsibility of the trigeminal nerve. The sensory root transmits the impulses to the *principal sensory nucleus of trigeminal nerve.* The axons of related cells decussate and join the medial lemniscus to reach the thalamus. From the thalamus, the fibers of the last link reach the postcentral gyrus.

The *reticular formation*, **formatio reticularis**

The reticular formation appears as aggregation of small numerous nuclei situated in the central compartments of the brainstem. The nuclei comprise numerous small and large neurons with branching processes that form vast networks.

The sensory pathways for specific sensitivity (pain, temperature, vision and hearing) maintain vast communication with the neurons of the reticular formation at relay points. The reticular formation delays the sensory impulses being non-specific afferent system of the brain.

Impulses generated by the reticular formation provide general background activation of the entire CNS including even the cerebral cortex.

The lateral portions of the reticular formation contain the accepting zones and the central portions contain the efferent areas that give the fibers to the cerebellum, the spinal cord (the *reticulospinal tract*), the corpus striatum, the thalamus and the cerebral cortex.

The impulses of the reticular formation unlike those of the afferent pathways feature diffuse deployment in the entire cortex. This provides generalized activation of the cortical neurons and thus adequate perception of the specific sensory impulses. The cerebral cortex in turn regulates activity of the reticular formation cells.

The nuclei of the reticular formation are of great importance as the relay points for the impulses that run to the hypothalamus, the corpus striatum and the limbic system. These compartments in turn pass the influence on the autonomic and motor neurons via the reticular formation (the *reticulospinal tract*).

THE EFFERENT PATHWAYS

The motor pathways comprise two systems of descending fibers: 1) the pyramidal system that conducts voluntary motor impulses from the cerebral cortex and 2) extrapyramidal system that deals with the basal nuclei. The systems maintain interrelations and act as a single unit.

1. The pyramidal system

The pyramidal fibers conduct the impulses for well-coordinated target-

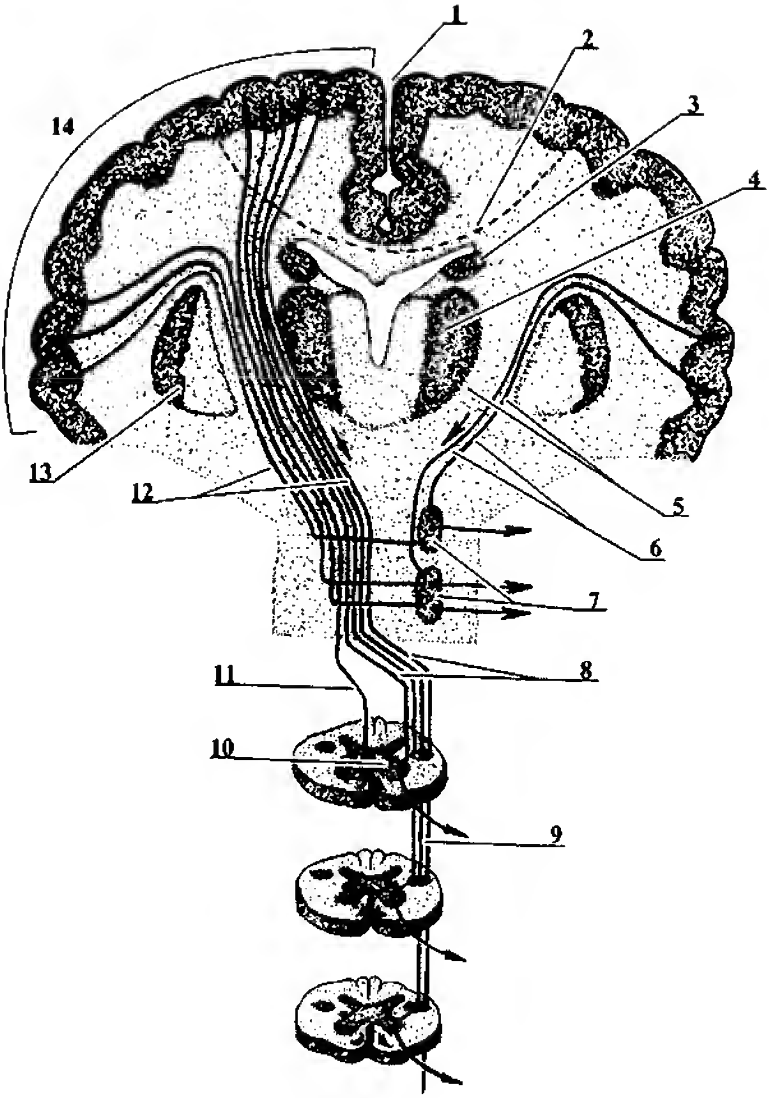

Fig. 27. The pyramidal tracts (scheme). 1 — fissura longitudinalis cerebri; 2 — fibrae corporis callosi; 3 — nucleus caudatus; 4 — thalamus; 5 — capsula interna; 6 — fibrae corticonucleares; 7 — рухові ядра черепних нервів; 8 — decussatio pyramidum; 9 — tractus corticispinalis lateralis; 10 — посегментне перехрестя tractus corticospinalis anterior; 11 — tractus corticospinalis anterior; 12 — fasciculus piramidalis; 13 — nucleus lentiformis; 14 — gyrus precentralis.

ed voluntary movements. The system is represented with the *pyramidal fasciculus*, **fasciculus pyramidalis** subdivided into the *corticonuclear fibers* and the *corticospinal fibers*.

The *first neurons* of this chain are the gigantic pyramidal cells (of Betz) situated in the precentral gyrus and the paracentral lobule (the motor areas). The axons of the cells form the pyramidal fasciculus that passes through the genu and the anterior potion of the internal capsule and descends to the brainstem and the spinal cord. Some fibers decussate yet in the brainstem and terminate on the motor nuclei of the cranial nerves that reside within the midbrain (the 3rd and the 4th pairs), within the pons (the 5th, the 6th, the 7th and the 8th pairs) and within the medulla oblongata (the 9th, the 10th, the 11th and the 12th pairs). This portion of the pyramidal fasciculus constitutes the *corticonuclear fibers*.

The motor cells of the respective nuclei of the cranial nerves are the *second neurons* of the chain. Their axons quit the brainstem as he respective cranial nerves and reach the areas of responsibility.

The larger portion of the fibers descends to the pyramids of the medulla oblongata as the *corticospinal fibers*. On reaching the spinal cord, about 80% of the fibers decussate (the *decussation of pyramids*) and enter the lateral funiculus to form the *lateral corticospinal tract*. The rest of fibers proceed to the anterior funiculus directly to form the *anterior corticospinal tract*.

The fibers of both tracts enter each segment separately; the fibers of the anterior corticospinal tract decussate as they reach the destination point.

Clinical applications

As the result of massive decussation of the corticospinal fibers, the limbs appear to be under control of the contralateral hemisphere. The muscles of the trunk, the diaphragm and the muscles of perineum are supplied by both decussated and non-decussated fibers. That is why injury to the pyramidal tracts results in central paralysis of both limbs while the diaphragm and the muscles of trunk manifest little malfunctioning.

The motor neurons of the anterior grey columns are the *second neurons* of the chain. Their axons quit the spinal cord and join the spinal nerves to reach the area of responsibility.

2. The extrapyramidal system

The extrapyramidal system ensures adequate muscle tonus and tuning of the motor apparatus. It automatically sets the muscles to background alert mode necessary for fast highly differentiated movements specified by the pyramidal system. The extrapyramidal system acts in concert with the pyramidal system; both systems constitute a single whole.

The nuclei of the extrapyramidal system

The extrapyramidal system comprises the nuclei as follows:

- the *corpus striatum* (Lat. Id.), it consists of the caudate and the lentiform nuclei (they form the striopal-

lidary system). The nuclei are the superior extrapyramidal centers;

- the *subthalamic nucleus*, **nucleus subthalamicus** (nucleus of Luys) situated within the ventral thalamus;
- the *red nucleus*, **nucleus ruber** situated within the tegmentum of midbrain;
- the *substantia nigra* (Lat. Id.), a black crescent-shaped plate that delimits the tegmentum and the base of cerebral peduncle;

The extrapyramidal nuclei feature vast associations between each other and with the cerebral cortex and the cerebellum. The latter provides movements coordination and thus is included into the system as well as the nuclei of the *tectal plate*, the vestibular nuclei, the inferior olive and the reticular formation.

The extrapyramidal pathways

The *extrapyramidal pathways* conduct the impulses from the subcortical nuclei to the motor nuclei of the cranial nerves and the motor nuclei of the anterior grey columns (of the spinal cord). They comprise the fibers as follows:

- the *rubrospinal tract*, **tractus rubrospinalis** that arises from the red nucleus. The fibers of the tract decussate and proceed to the lateral funiculus of the spinal cord. The tract is of certain importance because it conducts the impulses from the corpus striatum and the cerebellum;
- the *tectospinal tract*, **tractus tectospinalis** that arises from the tectum of midbrain (the nuclei of colliculi);
- the *vestibulospinal tract*, **tractus vestibulospinalis** that arises from the vestibular nuclei;
- the *olivospinal tract*, **tractus olivospinalis** that arises from the inferior olivary nucleus;
- the *reticulospinal tract*, **tractus reticulospinalis** that arises from the reticular formation of the brainstem. The corpus striatum lacks direct association with the spinal cord therefore its impulses relay in the subcortical nuclei and the nuclei of the reticular formation. The reticulospinal tract thus appears to be quite an important extrapyramidal pathway.

THE MENINGES, MENINGES

The spinal cord and the brain are enfolded into three connective tissue layers – the dura mater, the arachnoid mater and the pia mater.

THE DURA MATER

The dura mater appears as dense fibrous outer layer of the spinal cord and the brain.

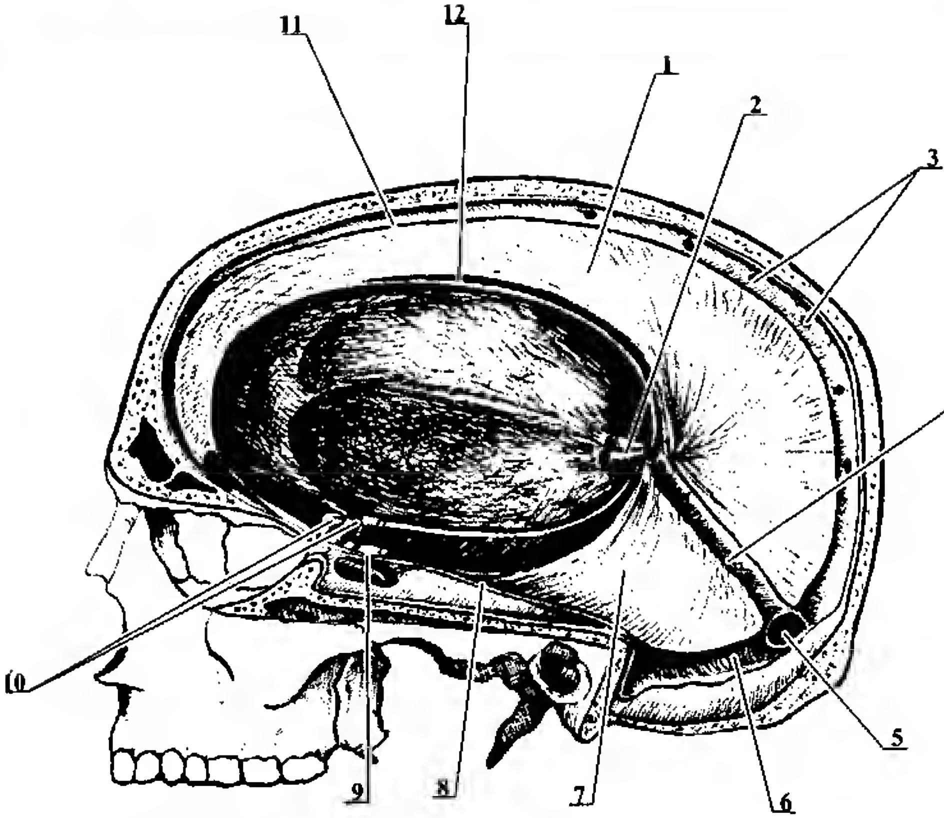

Fig. 28. The processes and the sinuses of dura mater. 1 — falx cerebri; 2 — v. cerebri interna; 3 — granulationes arachnoidales; 4 — sinus rectus; 5 — confluens sinuum; 6 — sinus occipitalis; 7 — tentorium cerebelli; 8 — sinus petrosus superior; 9 — diaphragma sellae; 10 — a. carotis interna et n. opticus; 11 — sinus sagittalis superior; 12 — sinus sagittalis inferior.

The *spinal dura mater*, **dura mater spinalis**, the part related to the vertebral canal features two plates — the external and the internal. The external layer is the modified periosteum of the vertebrae. It invests the vertebral canal fixing firmly to its walls. The internal plate enfolds the spinal cord. A space between the two layers is called the *epidural space*, **spatium epidurale**. It houses the internal vertebral venous plexuses. Laterally, the spinal dura mater attaches to the margins of intervertebral foramina and even escapes from the vertebral canal expanding onto the initial portion of each nerve.

Superiorly, the *spinal dura mater* attaches to the margin of the foramen magnum and becomes continuous with the cranial dura mater. Inferiorly, it terminates with a cul-de-sac at the level of S2.

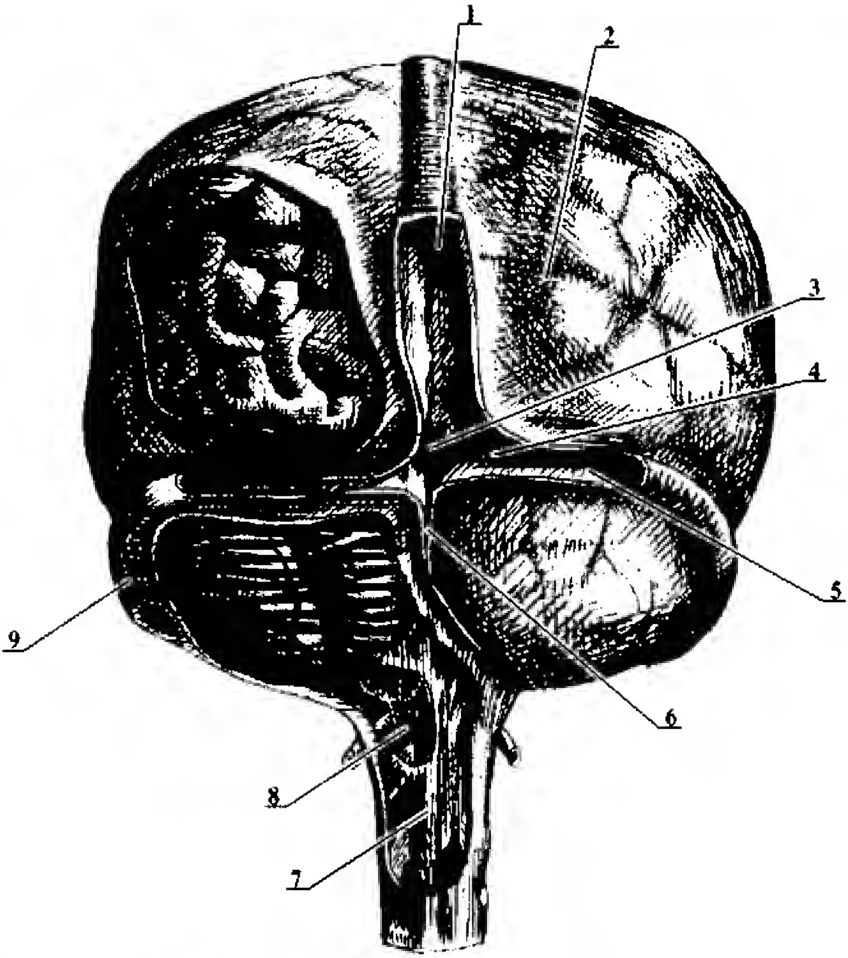

Fig. 29. The dura mater, the arachnoid mater and the confluence of sinuses. 1 — sinus sagittalis superior; 2 — dura mater encephali; 3 — sinus rectus; 4 — confluens sinuum; 5 — sinus transversus; 6 — sinus occipitalis; 7 — arachnoidea spinalis; 8 — cisterna cerebellomedullaris; 9 — sinus sigmoideus.

The *cranial dura mater*, **dura mater cranialis** comprises only one layer, which invests the cranial cavity from inside and therefore serves as cranial endosteum. The cranial dura mater fixes firmly to the bones of cranial base while attachment to the cranial vault remains quite loose except for the cranial sutures.

The cranial dura mater gives off several outgrowths found between the brain compartments:

- the *falx cerebri* (Lat. Id.) the dura mater duplication that runs along

the longitudinal fissure. Inferiorly it reaches the corpus callosum;

- the *tentorium cerebelli* (Lat. Id.) an outgrowth that separates the occipital lobes from the cerebellum;
- the *falx cerebelli* (Lat. Id.) a small process that runs sagittally between the cerebellar hemispheres;
- the *diaphragma sellae* (Lat. Id.) a portion of the dura mate that expand between the clinoid processes of the sphenoid. It features the opening that passes the infundibulum on its way to the pituitary.

The dura mater also splits to form the endothelium-lined cavities called the *dural venous sinuses*, **sinus durae matris**. They serve venous blood drainage from the cranial cavity (see page 292)

THE ARACHNOID MATER, ARACHNOIDEA MATER

The arachnoid mater appears as a very thin connective tissue layer found between the dura mater and the pia mater. Unlike the pia mater, the arachnoid mater never enters the fossae, sulci and fissures of the brain so one can distinguish a space between the two coverings – the *subarachnoid space*, **spatium subarachnoideum** filled with the *cerebrospinal fluid*, **liquor cerebrospinalis.**

The subarachnoid cisterns, cisternae subarachnoideae

The subarachnoid space features several extensions in the areas related to the fossae, excavations and deep fissures. They are the subarachnoid cisterns. The greatest cisterns are like the following:

- the *posterior cerebellomedullary cistern*, **cisterna cerebellomedullaris magna,** the extension situated between the cerebellum and the medulla oblongata[1];
- the *cistern of lateral cerebral fossa*, **cisterna fossae lateralis cerebri,** the cavity related to the respective fossa;
- the *chiasmatic cistern*, **cisterna chiasmatica**, the cistern found in the area of optic chiasm;
- the *interpeduncular cistern*, **cisterna interpeduncularis** found between the cerebral peduncles.

The granulations

The cranial arachnoid mater features villous outgrowths called the *arachnoid granulations*, **granulationes arachnoideae**[2]. They mostly run along the superior sagittal sinus. The granulations penetrate the cranial dura mater and protrude into the sinus lumen or into the neighboring *lateral lacunae*. The granulations are believed to serve drainage of the CSF into the dural sinuses.

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[1] this cistern is of a certain clinical significance because it allows suboccipital puncturing of the cranial subarachnoid space for CSF sampling. The needle is inserted between the atlas and the axis

[2] the Pacchionian granulations

The *spinal arachnoid mater,* **arachnoidea mater spinalis** features the *denticulate ligaments,* **ligamenta denticulatae** – the frontally oriented processes that attach the pia mater to the dura mater. They reside between the anterior and the posterior roots. The lateral portions feature separate fingers that affix to the dura mater. The denticulate ligaments split the spinal subarachnoid space into anterior and posterior portions that maintain communication.

Superiorly, the spinal subarachnoid space becomes continuous with the cranial subarachnoid space.

THE PIA MATER

The pia mater is the thinnest inner covering adherent to the cerebral surface. It enters into all sulci and fissures and participates in formation of the choroid plexuses and the ventricular investment. Numerous embedded blood vessels carry the pia mater into the ventricles where it forms the following plexuses:

- the *choroid plexus of lateral ventricle*ё **plexus choroideus ventriculi lateralis** that runs from the interventricular foramen down to the inferior horn;
- the *choroid membrane of third ventricle,* **tela choroidea ventriculi tertii** that forms the roof of the third ventricle;
- the *choroid plexus of fourth ventricle,* **plexus choroideus ventriculi quarti** situated next to the inferior medullary velum.

The plexuses have numerous villi with featured dense capillary networks. The villi produce the cerebrospinal fluid.

Circulation of the cerebrospinal fluid

The *cerebrospinal fluid,* **liquor cerebrospinalis** produced by the villi of the choroid plexuses fills all ventricles and the entire subarachnoid space. Its volume is about 150-200 ml. the fluid produced within the lateral ventricles drains to the third ventricles via the interventricular foramina. From the third ventricle, the fluid drains to the fourth ventricle via the cerebral aqueduct. The roof of the fourth ventricle features the *apertures* (**aperturae lateralis et mediana**) that drain the CSF to the subarachnoid space. The subarachnoid space provides two principal drainage routes: the arachnoid granulations (related to the cranial cavity) and the perineural spaces (related to the vertebral canal).

Practice questions

1. Discuss embryological classification of the brain and derivatives of the cerebral vesicles.
2. Discuss the compartments of the brain according to anatomical classification.
3. Describe the compartments and development of the brainstem.
4. Describe the external features, the boundaries and development of the medulla oblongata.

5. Describe the internal features of the medulla oblongata. Discuss its functional significance.
6. Describe the external features, the boundaries and development of the pons.
7. Describe the internal features of the pons. Discuss its functional significance.
8. Describe formation, contents and topography of the medial lemniscus. Discuss its functional significance.
9. Describe the external features, the boundaries and development of the cerebellum.
10. Describe the internal features of the cerebellum Discuss its functional significance.
11. Describe the boundaries and relief of the rhomboid fossa. Describe topography of the nuclei of cranial nerves.
12. Describe development, topography, walls and featured communications of the fourth ventricle.
13. Describe development, boundaries, external features and compartments of the midbrain
14. Discuss external and internal features of the tectum of midbrain.
15. Discuss external and internal features of the tegmentum of midbrain.
16. Describe compartments, boundaries, structure of featured grey and white matter and topography of related pathways of the cerebral peduncles.
17. Name the principal parts of the diencephalon.
18. Describe the external features and the nuclei of thalamus. Discuss significance of the featured nuclei.
19. Describe the parts of metathalamus and discuss their functional significance.
20. Describe the parts of epithalamus and discuss their functional significance.
21. Describe topography and function of the pineal gland.
22. Describe external features of hypothalamus.
23. Describe topography, parts and function of the pituitary gland.
24. Describe the hypothalamic nuclei. Discuss their functional significance. Describe the hypothalamo-hypophyseal system.
25. Describe development, walls and communications of the third ventricle.
26. Name the parts of the telencephalon.
27. Describe the cerebral hemispheres with related surfaces, principal parts and the boundaries
28. Describe the sulci and gyri of the superolateral face of cerebral hemispheres.
29. Describe the sulci and gyri of the medial surface of cerebral hemispheres.
30. Describe the sulci and gyri of the inferior surface of cerebral hemispheres.
31. Describe structure of the cerebral cortex. Discuss V.A. Betz's researches.
32. Give definition of the analyzer.

33. Describe location of the cortical ends of analyzers.
34. Describe structure and functions of the corpus callosum.
35. Describe structure and functions of the fornix.
36. Describe structure and functions of the rhinencephalon.
37. Discuss topography, compartments and functional significance of the basal nuclei.
38. Discuss topography, compartments and functional significance of the corpus striatum.
39. Describe the parts and functional significance of the limbic system.
40. Describe development, topography, walls and featured communications of the lateral ventricles.
41. Describe topography, walls and communications of the anterior horn of lateral ventricle.
42. Describe topography, walls and communications of the posterior horn of lateral ventricle.
43. Describe topography, walls and communications of the inferior horn of lateral ventricle.
44. Describe topography, walls and communications of the central part of lateral ventricle.
45. Discuss classification and functional significance of the white mater of cerebral hemispheres.
46. Discuss classification and functional significance of the association fibers.
47. Discuss commissural fibers and their functional significance.
48. Discuss projection fibers and their functional significance.
49. Describe topography, parts and related pathways of the internal capsule.
50. Give definition of the neural pathways and discuss their classification.
51. Discuss proprioceptive pathways.
52. Discuss exteroceptive pathways.
53. Describe topography, structure, associations and functional significance of the reticular formation.
54. Describe the corticospinal tract.
55. Describe the corticonuclear tract.
56. Discuss the extrapyramidal system.
57. Describe the extrapyramidal pathways.
58. Describe the spinal meninges with pertaining spaces and their contents.
59. Describe the cranial meninges.
60. Name the differences between the spinal and the cranial meninges.
61. Describe the cranial dura mater and related projections.
62. Describe the spaces between the meninges and their contents.
63. Describe the subarachnoid space and related extensions (the cisterns).
64. Describe production and circulation of the cerebrospinal fluid.

THE PERIPHERAL NERVOUS SYSTEM

GENERAL DATA

The peripheral nervous system comprises the spinal and the cranial nerves, the ganglia, the autonomic nervous plexuses and the nerve terminations.

Structure of the nerve

The *nerve*, **nervus** constitutes the bundle of neural fibers enfolded into connective tissue tunics. The tunics are referred to as the endoneurium, the perineurium and the epineurium:

- the *endoneurium* (Lat. Id.) is a thin connective tissue layer that enfolds the first-order bundles;
- the *perineurium* (Lat. Id.) is a dense, resilient tunic that enfolds several bundles. The perineurium forms the canals (the perineural sheaths) filled with fluid;
- the *endoneurium* (Lat. Id.) is an outer loose connective tissue tunic.

The nerves are abundantly nourished by the *vessels of nerves*, **vasa nervosum** that arise from the nearby sources. The tunics also enfold the nerve terminations.

Internal structure of the nerve

In their researches, V.M. Shevkunenko, O.M. Maximenko, M.I. Odnoralov and others demonstrated that after stripping of the epineurium (by means of acid processing) the nerve appears as a plexus formed of separate perineural sheaths. As far as the perineural fibers anastomose, the fibers may pass from one sheath to another. Network features are variable and depend on the bundle thickness in the following manner: density and width of the network increase with the bundle thinning and vice versa.

Clinical applications

In order to restore the damaged nerve one can employ stretching because the perineurium is resilient enough and some fibers are compacted in spiral fashion within the sheath. Regeneration takes quite a long time and depends rather on damage severity.

In 1977, F.M. Khitrov offered a new modality aimed at fastening of nerve regeneration. The novelty stands for suturing of the proximal end of destroyed nerve to the artery that nourishes the organ supplied by the damaged nerve. This results in faster regeneration of the nerve.

Myelinated and non-myelinated nerve fibers

The myelinated fibers are thicker and whitish; they are well distinguishable. The non-myelinated (grey) fibers are thinner and less apparent as compared to the myelinated fibers. Such fibers belong mostly to the autonomic nervous system.

The nerve usually comprises both myelinated and non-myelinated fibers yet some nerves feature prevailing type of fibers. In this case, we distinguish the myelin-type nerves and non-myelin-type nerves.

Impulse conduction rate varies depending on the fiber type. Thick myelinated fibers (8-20 μm) feature high rate (up to 30 mps) while the non-myelinated only 0.7-0.3 mps.

The sensory, motor and mixed nerves

Depending on functional type of the featured fibers, one can distinguish the sensory, the motor and the mixed nerves:

- the *motor nerve*, **nervus motorius** comprises the motor fibers that carry the impulses to the muscles and the glands;
- the *sensory nerve*, **nervus sensorius** comprises the fibers that carry the impulses from the receptors to the central nervous system;
- the *mixed nerve*, **nervus mixtus** comprises both types of fibers; most of the nerves distinguished are the mixed nerves.

The ganglia

The *ganglion* (Lat. Id.) consists of the neurons enfolded into the *capsule of ganglion*, **capsula ganglii**. The principal types of the ganglia are the craniospinal ganglia and the autonomic ganglia:

- the *craniospinal sensory ganglia*, **ganglia sensoria craniospinale** feature the sensory pseudounipolar cells. They are subdivided into the following types:
  a) the *spinal ganglia*, **ganglia sensoria nervi spinales** that belong to the spinal nerves. They give rise to their sensory fibers;
  b) the *cranial sensory ganglia*, **ganglia sensoria nervi craniales** that belong to the cranial nerves. They also give rise to the sensory fibers;
- the *autonomic ganglia*, **ganglia autonomica** that consist of the autonomic neurons. They represent the peripheral compartment of the autonomic nervous system and give rise to the postganglionic fibers.

The autonomic fibers form the autonomic plexuses within the viscera and along the blood vessels.

THE CRANIAL NERVES, NERVI CRANIALES

There are twelve pairs of cranial nerves that arise directly from the brain (Fig. 30):

I. the *olfactory nerve*, **nervus olfactorius;**
II. the *optic nerve*, **nervus opticus**;
III. the *oculomotor nerve*, **nervus oculomotorius;**
IV. the *trochlear nerve*, **nervus trochlearis**;

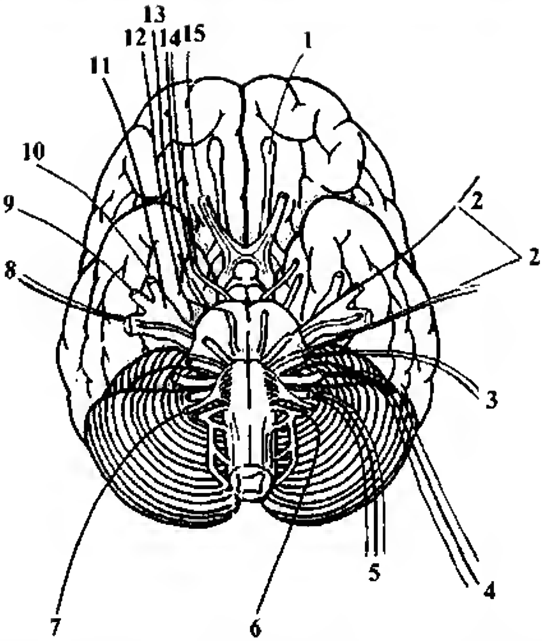


Fig. 30. The origination points of the cranial nerves and fibers contents. 1 — n. olfactorius (I); 2 — n. facialis(VII); 3 — n. vestibulocochlearis (VIII); 4 — n. glossopharyngeus (IX); 5 — n. vagus (X); 6 — n. accessorius (XI); 7 — n, hypoglossus (XII); 8 — n. mandibularis; 9 — n. maxillaris; 10 — n. ophthalmicus; 11 — ganglion trigeminale; 12 — n. abducens (VI); 13 — n. trochlearis (IV); 14 — n. oculomotorius (III); 15 — n. opticus (II) (Червоним кольором позначено рухові, синім — чутливі, зеленим — передвузлові парасимпатичні волокна).

V. the *trigeminal nerve*, **nervus trigeminus**;
VI. the *abducent nerve*, **nervus abducens**;
VII. the *facial nerve*, **nervus facialis**;
VIII. the *vestibulocochlear nerve*, **nervus vestibulocochlearis**;
IX. the *glossopharyngeal nerve*, **nervus glossopharyngeus**;
X. the *vagus nerve*, **nervus vagus**;
XI. the *accessory nerve*, **nervus accessories**;
XII. the *hypoglossal nerve*, **nervus hypoglossus**.

The cranial nerves develop in tight association with several organs:

The pairs I, II and VIII develop in association with the sensory organs; the pairs I and II are plain projections of the brain and have no specific relay nuclei;

The pairs III, IV and VI supply the extrinsic muscles of eye and develop in association with the cranial myotomes;

The pair V is associated with the 1st (mandibular) visceral arch;

The pair VII is associated with the 2nd (hyoid) visceral arch;

The pairs IX, X and XI constitute the vagus group and develop in association with the branchial arches;

The pair XII develops from fused spinal motor roots.

I. The olfactory nerve, nervus olfactorius

The olfactory nerve is the specific sensitivity nerve formed of 15-20 thin *olfactory nerves*, **nervi olfactorii**. The olfactory nerves are the central processes of sensory bipolar neurons related to olfactory region of nasal mucosa (the first neuron of the chain). The nerves enter the cranial cavity via the cribriform plate and synapse with the cells of the *olfactory bulb*, **bulbus olfactorius** (the second neuron). The axons of the second neurons form the *olfactory tract*, **tractus olfactorius**, which in turn becomes continuous with the *olfactory tract*, **tractus olfactorius**. The olfactory tract terminates with the *olfactory trigone*, **trigonum olfactorium**, which houses the third neurons. The olfactory trigone gives rise to three olfactory stria — the lateral, the medial and the intermediate that conduct impulses to the cortical ends of the olfactory analyzer — the *uncus* (Lat. Id.) of the parahippocampal gyrus. The olfactive substances suspended in the air stimulate the peripheral process of the olfactory cells that generate the response for the brain. Injury to the olfactory nerve may result in reduced sense of smell — hyposmia or even in its complete absence — anosmia.

II. The optic nerve, nevus otpicus

The optic nerve is also a specific sensitivity nerve. It is formed of the axons of ganglionic cells of retina that join in the area of the optic disc (the physiological cup). The nerve penetrates the tunics of the eyeball and enters the cranial cavity via the *optic canal*, **canalis opticus**. The two nerves join in the area of the tuber cinereum to form incomplete decussation — the *optic chiasm*, **chiasma opticum** where only the fibers that arise from the medial portions of both retinas decussate. The optic chiasm actually gives rise to the optic pathway.

The fibers past the optic chiasm proceed as the *optic tract*, **tractus otpicus** that contains both contralateral and ipsilateral fibers. The optic tract loops around the cerebral peduncle and terminates within the subcortical visual centers: the lateral geniculate body, the pulvinar of thalamus and the superior colliculi of tectal plate. The axons from the lateral geniculate body and the pulvinar proceed to the cortical end of visual analyzer, which resides within the marginal area of the calcarine sulcus of occipital lobe. The axons of the superior colliculi run to the parasympathetic nuclei of the oculomotor nerve. The parasympathetic fibers of the oculomotor nerve in turn run to the intrinsic muscles of eye: the sphincter pupillae and the ciliary muscle. The circuit described constitutes the pupillary reflex arc. Apart from this, some fibers from the superior colliculi join the *tectospinal tract*, **tractus tectospinalis** responsible for

so called 'start reflex' — the instant response to sudden sound stimuli.

Injury to the optic nerve or the retina may result in vision loss or even in complete blindness (amaurosis).

III. The oculomotor nerve, nervus oculomotorius

The oculomotor nerve is a mixed nerve, which features the motor and the parasympathetic fibers.

The nuclei

The *nucleus of oculomotor nerve,* **nucleus motorius nervi oculomotorii** resides within the midbrain below the cerebral aqueduct, on the level of the superior colliculi. The *accessory nucleus of oculomotor nerve,* **nucleus accessorius nervi oculomotorii** (of Yakubovich), which is the parasympathetic nucleus resides medially from the motor nucleus.

Topography

The oculomotor nerve becomes evident in the area of the *interpeduncular fossa.* It arises from the medial surface of the cerebral peduncle. The nerve further traverses the external wall of the cavernous sinus and enters the orbit via the superior orbital fissure. Within the orbit, the nerve gives off two branches: the *superior branch,* **ramus superior** and the *inferior branch,* **ramus inferior**. The superior branch supplies the superior rectus and the levator palpebrae superioris while the inferior branch supplies the inferior rectus, the medial rectus and the inferior oblique (they all are the extrinsic muscles of eyeball).

The parasympathetic fibers

The oculomotor nerve comprises the preganglionic fibers from the accessory nucleus of oculomotor nerve. Upon entering the orbit, these fibers part the motor fibers and reach the *ciliary ganglion,* **ganglion ciliare** situated laterally from the optic nerve. The ganglion fives off the postganglionic fibers that join the *short ciliary nerves,* **nervi ciliares breves** and supply the ciliary muscle and the sphincter pupillae.

Clinical applications

Injury to the oculomotor nerve results in squint, ptosis (depression of the superior eyelid), dilation of the pupil and accommodation impairment.

IV. The trochlear nerve, nervus trochlearis

The trochlear nerve is the purely motor nerve.

The *nucleus of trochlear nerve,* **nucleus nervi trochlearis** resides within the tegmentum of cerebral peduncles below the cerebral aqueduct, on the level of inferior colliculi. This thin nerve arises from the dorsal surface of brainstem namely laterally from the frenulum of superior medullary velum. On the way to destination point, the nerve loops around the cerebral peduncle, traverses the lateral wall of the cavernous sinus and enters the orbit via the superior orbital fissure. It supplies solely the *superior oblique,* **musculus obliquus superior** (Fig. 31).

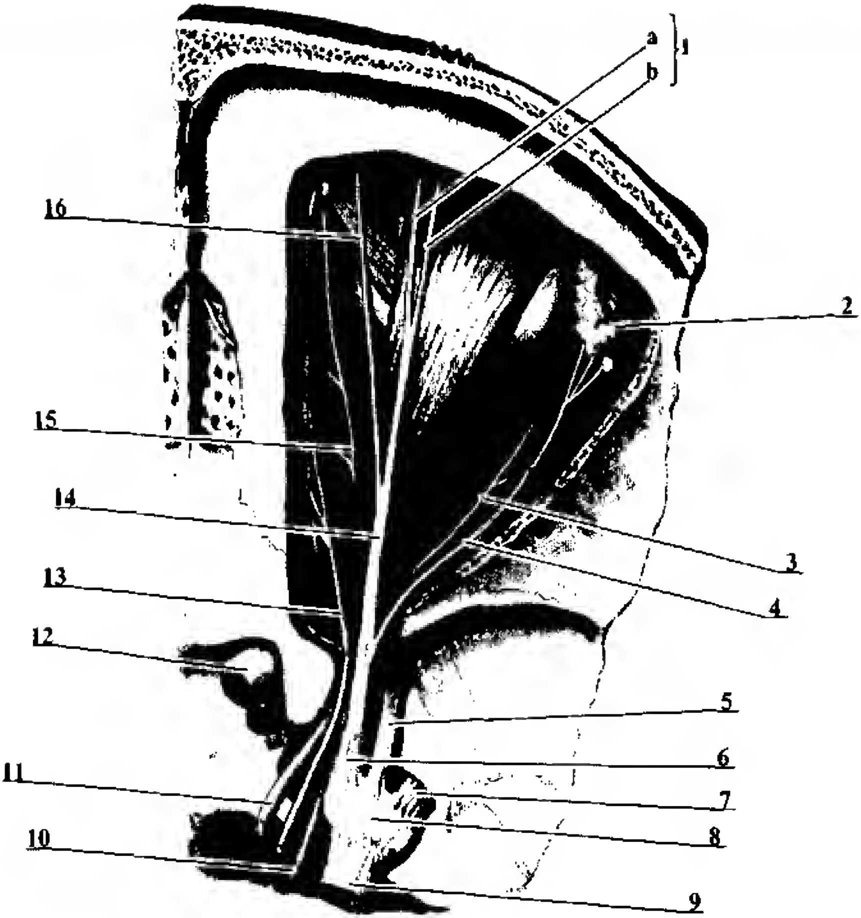


Fig. 31. The nerves of right orbit, superior view (the upper wall of orbit is removed). 1 — n. supraorbitalis (a — r. medialis, b — r. lateralis); 2 — gl. lacrimalis; 3 — n. abducens; 4 — n. lacrimalis; 5 — n. maxillaris; 6 — n. ophtalmicus; 7 — n. mandibularis; 8 — gangl. trigeminale; 9 — radix sensoria n. trigemini; 10 — n. abducens; 11 — n. oculomotorius; 12 — n. opticus; 13 — n. trochlearis; 14 — n. frontalis; 15 — n. nasociliaris; 16 — n. supratrochlearis.

V. The trigeminal nerve, nervus trigeminus

The trigeminal nerve is one of the greatest cranial nerves. It is a mixed nerve that comprises the sensory and the motor fibers. Apart from the somatic fibers, the nerve accepts the autonomic fibers from the oculomotor nerve, the facial nerve and the glossopharyngeal nerves.

The nuclei of trigeminal nerve

The trigeminal nerve features one motor and three sensory nuclei.

The *motor nucleus of trigeminal nerve*, **nucleus motorius nervi grigemini** resides within the tegmentum of pons. Its fibers supply the masticatory muscles and some other.

The sensory nuclei are like the following:

1) the *principal sensory nucleus of trigeminal nerve*, **nucleus principalis nervi trigemini** situated within the pons. It accepts the fibers that transmit tactile and proprioceptive sensitivity impulses;

2) the *spinal nucleus of trigeminal nerve*, **nucleus spinalis nervi trigemini** situated both within the medulla oblongata and the spinal cord. It accepts the fibers that conduct pain and temperature sensitivity;

3) the *mesencephalic nucleus of trigeminal nerve*, **nucleus mesencephalicus nervi trigemini** situated within the midbrain laterally from the cerebral aqueduct. The neurons of the nucleus are the sensory pseudounipolar cells identical to the cells of the trigeminal ganglion. Their peripheral processes terminate at muscular proprioceptors. The nucleus thus appears as the sensory ganglion embedded into the brainstem.

The roots and the sensory ganglion of the trigeminal nerve

The nerve becomes evident between the pons and the middle cerebellar peduncle with two roots — the sensory and the motor:

- the *sensory root*, **radix sensoria** rather thick, it consists of the fibers that arise from the trigeminal ganglion and terminate within the sensory nuclei;
- the *motor root*, **radix motoria** much smaller than the sensory root, it arises from the motor nucleus of the nerve and joins its third branch;
- the *trigeminal ganglion* (the Gasserian ganglion), **ganglion trigeminale (Gasseri)** well distinguishable, it resides on the apex of the petrous part of temporal bone (on the floor of the trigeminal impression). It occupies the cavity formed of split dura mater (the *trigeminal cavity*) (Fig. 32). The ganglion comprises the sensory pseudounipolar cells with the central and the peripheral processes featured. The central processes for the *sensory root*, **radix sensoria** and the peripheral processes form majority of the nerve branches that reach respective areas of the skin and the mucosa to terminate with the receptor cells.

The branches of the trigeminal nerve

The trigeminal nerve features three branches as follows:

1) the *ophthalmic nerve* — the first branch;

2) the *maxillary nerve* — the second branch;

3) the *mandibular nerve* — the third branch.

All these branches comprise the fibers of the trigeminal ganglion and

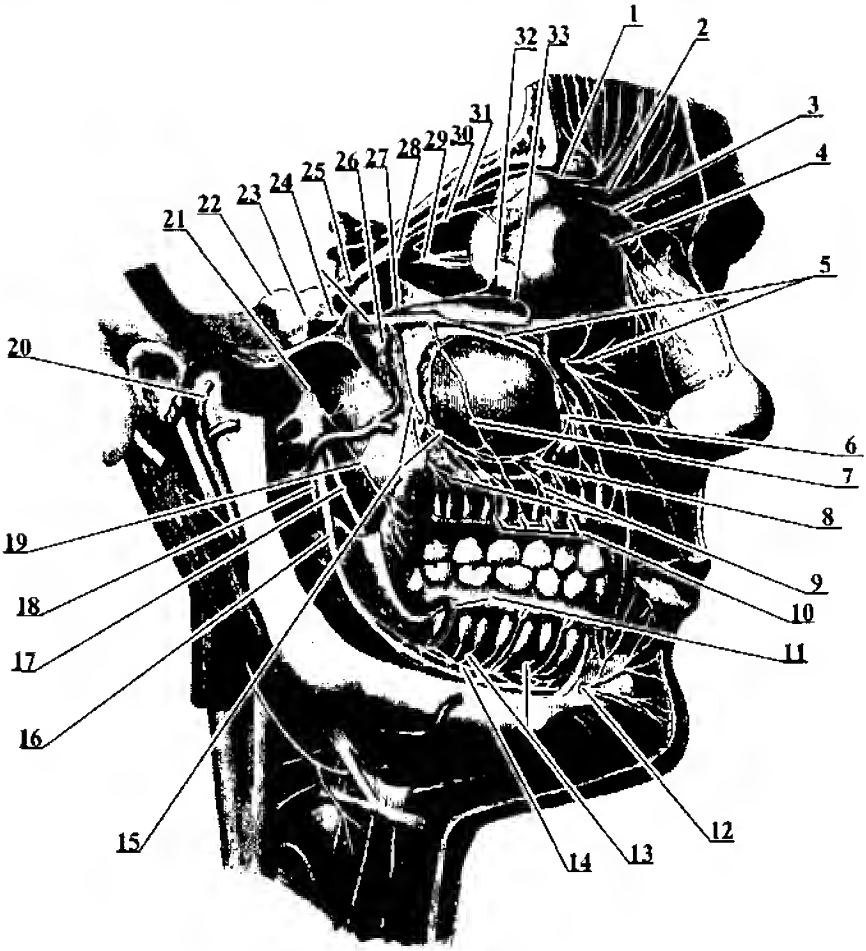


Fig. 32. The trigeminal nerve, nervus trigeminus. 1 — n. supraorbitalis (r. lateralis); 2 — n. supraorbitalis (r. medialis); 3 — n. supratrochlearis; 4 — n. infratrochlearis; 5 — n. infraorbitalis; 6 — rr. alveolares superiores anteriores; 7 — r. alveolaris superior medius; 8 — plexus dentalis superior; 9 — rr. dentales superiores; 10 — rr. gingivales superiores; 11 — rr. gingivales inferiores; 12 — n. mentalis; 13 — rr. dentales inferiores; 14 — plexus dentalis inferior; 15 — rr. alveolares superiores posteriores; 16 — nn. alveolaris inferior; 17 — n. lingualis; 18 — n. mylohyoideus; 19 — n. buccalis; 20 — n. auriculotemporalis; 21 — n. mandibularis; 22 — radix sensoria n. trigemini; 23 — gangl. trigeminale; 24 — n. maxillaris; 25 — n. ophtalmicus; 26 — gangl. pterygopalatum; 27 — n. zygomaticus; 28 — n. nasociliaris; 29 — gangl. ciliare; 30 — n. lacrimalis; 31 — n. frontalis; 32 — r. communicans cum n. zygomatico; 33 — n. zygomaticotemporalis.

thus are the sensory nerves yet the third branch accepts the entire motor root so the mandibular nerve appears as mixed branch. Before escape from the cranial cavity, each branch gives off thin meningeal branches (like the tentorial branch of the ophthalmic nerve) that supply the related dura mater. Each branch of the nerve is associated with the parasympathetic ganglion via the sensory root. Each parasympathetic ganglion features two more roots – the sympathetic root (given by the neighboring periarterial plexus) and the parasympathetic root (give by the III, VII and IX cranial nerves). All five cranial parasympathetic ganglia are associated with the trigeminal nerve: the ophthalmic nerve maintains association with the *ciliary ganglion*, **ganglion ciliare**, the maxillary nerve – with the *pterygopalatine ganglion* and the mandibular nerve – with the *otic*, the *submandibular* and the *sublingual ganglia*.

1. The ophthalmic nerve, nervus opthalmicus

The ophthalmic nerve is purely sensory branch of the trigeminal nerve. It arises from the ganglion and proceeds to the orbit via the superior orbital fissure. Before entering the orbit, the nerve splits into three more nerves – the frontal nerve, the lacrimal nerve and the nasociliary nerve:

- the *frontal nerve*, **nervus frontalis** is the largest of the listed; it runs midline along the superior orbital wall and splits into the *supraorbital nerve*, **nervus supraorbitalis** and the *supratrochlear nerve*, **nervus supratrochlearis**. The nerves escape from the orbit via the supraorbital notch and the frontal notch respectively and terminate within the skin of forehead, the root of nose, the superior eyelid with related conjunctiva in the medial angle of eye (Fig. 31, 32);
- the *nasociliary nerve*, **nervus nasociliaris**, it runs medially and branches into the following nerves:

1) the *anterior* and *posterior ethmoidal nerves*, **nervi ethmoidales anterior and posterior** that supply the ethmoidal cells, the sphenoidal sinus and the anterior portion of the nasal mucosa;
2) the *long ciliary nerves*, **nervi ciliares longi** that supply the eyeball tunics;
3) the *infratrochlear nerve*, **nervus infratrochlearis** that supplies the skin and related conjunctiva of the medial angle of eye together with deeper lacrimal sac;
4) the *sensory root of ciliary ganglion*, **radix sensoria ganglia ciliaris**;
5) the *short ciliary nerves*, **nervi ciliares breves**, the sensory fibers to the eyeball tunics (to the fibrous and the vascular layers).

The *ciliary ganglion*, ganglion ciliare

The nasociliary nerve is associated with a small parasympathetic ganglion situated within the orbit laterally from the optic nerve. The ganglion accepts the preganglionic parasym-

pathetic fibers that synapse with the pertaining cells. The postganglionic fibers join the *short ciliary nerves*, **nervi ciliares breves** and proceed to the eyeball. The ciliary ganglion also passes the sensory fibers that constitute the *sensory root of ciliary ganglion*, **radix sensoria ganglia ciliaris** (unlike the autonomic fibers, the sensory fibers simply traverse the ganglion and *never* synapse within it). Upon traversing the ganglion, the sensory fibers also join the *short ciliary nerves* to provide sensory nerve supply to the fibrous and the vascular layers of the eyeball.

- the *lacrimal nerve*, **nervus lacrimalis**, the last of the group, runs laterally to traverse the lacrimal gland and to terminate within the skin and conjunctiva of the lateral angle of the eye. Before entering the gland, the nerve anastomoses with the zygomatic nerve (of the maxillary nerve) via the *communicating branch with zygomatic nerve*, **ramus communicans cum nervo zygomatico** that carries the parasympathetic secretion fibers (from the facial nerve) to the lacrimal gland.

Before entering the orbit, the ophthalmic nerve gives the *tentorial nerve*, **ramus tentorius** that supplies the tentorium cerebelli.

2. The maxillary nerve, nervus maxillaries

The maxillary nerve is the second purely sensory branch of the trigeminal nerve. It also arises from the trigeminal ganglion and escapes from the cranial cavity via the *foramen rotundum*, which leads to the *pterygopalatine fossa*, **fossa pterygopalatina**. In the fossa, the nerve gives off its principal branches that run to the orbit and to the walls of the nasal and the oral cavities.

The branches of the maxillary nerve:

- the *infra-orbital nerve*, **nervus infraorbitalis** the largest nerve in the group. It arises immediately from the maxillary nerve and enters the orbit via the inferior orbital fissure. Within the orbit, the nerve runs along the *infra-orbital groove* then enters the *infra-orbital canal*, **canalis infraorbitalis** and reaches its responsibility area via the *infra-orbital foramen*, **foramen infraorbitale**. In the destination point, the nerve fans out to give numerous branches that supply the lower eyelid, the cheek, the nose and the upper lip. The branches are the *inferior palpebral branches*, the *external nasal branches* and the *superior labial branches*. Before reaching the superior orbital fissure the nerve gives off the *posterior superior alveolar branches*, **rami alveolares superiores posteriors** that reach the posterior teeth via the alveolar foramina of the maxillary tuberosity. Within the infraorbital canal, the nerve gives off the *middle* and the *anterior superior alveolar branches*, **rami alveolares superiores medii et anteriores** that also reach the upper teeth via

the respective alveolar foramina. These branches constitute the *superior alveolar nerves* group. On reaching the destination point, the branches anastomose to form the *superior dental plexus*, **plexus dentalis superior** that in turn gives the *superior dental branches*, **rami dentales superiores** and the *superior gingival branches*, **rami gingivales superiores** that supply the upper teeth with related gums.

- the *zygomatic nerve*, **nervus zygomaticus**, a smaller nerve that also enters the orbit. The nerve splits into the branches as follows:

1) the *communicating branch with zygomatic nerve* carries the parasympathetic postganglionic fibers from the pterygopalatine ganglion to the lacrimal gland;
2) the *zygomaticofacial branch*, **ramus zygomaticofacialis** escapes from the orbit via the opening of the same name. The branch supplies the skin of the zygomatic and the buccal regions;
3) the *zygomaticotemporal branch*, **ramus zygomaticotemporalis** also escapes from the orbit via the foramen of the same name. The nerve supplies the skin of the anterior portion of the temporal region;

- the *ganglionic branches to pterygopalatine ganglion*, **rami ganglionares ad ganglion pterygopalatinum**, the thin branches that traverse the pterygopalatine ganglion (See 'Parasympathetic nervous system' section). The sensory branches from the ganglion take two principal routes:

1) the *posterior superior medial* and *lateral nasal branches*, **rami nasals posteriores superiores mediales et laterals** that supply the mucosa of the posterior portion of nasal cavity;

2) the *greater palatine nerve* and the *lesser palatine nerves*, **nervus palatinus major et nervi palatini minors** that pass through the respective foramina and supply the mucosa of the palate.

Clinical applications

Anesthetizing of the upper anterior teeth is possible via the infra-orbital foramen while the upper posterior teeth may be anesthetized by infiltration of the maxillary tuberosity area. The middle teeth require both methods because of the dental plexus.

3. The mandibular nerve, nervus madibularis

The mandibular nerve is the third mixed branch of the trigeminal nerve; it features both sensory and the motor fibers that arise from the respective nuclei. The nerve escapes from the cranial cavity via the *foramen ovale* and reaches the *infratemporal fossa*, **fossa infratemporalis** where splits into the principal branches (the sensory, the motor and the mixed):

a) The sensory and the mixed branches:

- the *meningeal branch*, **ramus meningeus** returns to the cranial cavity via the foramen spinosum (together with the middle meningeal artery). The nerve supplies the dura mater of the middle cranial fossa;

- the *inferior alveolar nerve*, **nervus alveolaris inferior**, the greatest mixed branch of the nerve. It passes within the *mandibular canal* that terminates with the *mental foramen*, **formen mentale**. The terminal branch of the nerve – the *mental nerve*, **nervus mentalis** – supplies the skin of the chin and the lower lip. Within the canal, the nerve gives off the branches similar to those of the maxillary nerve. These branches form the *inferior dental plexus*, **plexus dentalis inferior** that gives the inferior dental and the gingival branches. Before entering the mandibular canal, the mandibular nerve gives the *nerve to mylohyoid*, **nervus mylohyoideus** that supplies the posterior belly of the digastric and the entire mylohyoid.

Clinical applications

Anesthetizing of the lower teeth is possible via the mental foramen.

- the *lingual nerve*, **nervus lingualis**, rather thick, is the sensory nerve. The nerve gives off the *lingual branches*, **rami linguales** to anterior two thirds of the lingual mucosa. The nerve transmits the impulses of pain, temperature and tactile sensitivity. The nerve also supplies the oral cavity floor mucosa and the lower gums (the *sublingual nerve*) and gives off the *ganglionic branches to submandibular* and *sublingual ganglia*, **rami ganglionares ad ganglia submandibularis et sublingualis**. The ganglia neighbor the respective salivary glands (See 'Parasympathetic nervous system' section). Upon traversing the ganglia, the sensory fibers supply the respective salivary gland.

Within the passage between the lateral and the medial pterygoid muscles, the lingual nerve accepts the *chorda tympani* (Lat. Id.) that originates from the facial (intermediate) nerve. The chorda tympani carries the sensory (gustatory) fibers to the lingual papillae (anterior two thirds of the tongue) and the parasympathetic fibers to the submandibular and the sublingual salivary glands (See 'The facial nerve').

- the *auriculotemporal nerve*, **nervus auriculotemporalis** is the last sensory nerve of the group. It arises with two roots that enfold the middle meningeal artery and reassemble into the single trunk that loops around the neck of mandible. The nerve penetrates the *parotid gland*, **glandula parotidea** to provide sensory nerve supply. The terminal branches supply the skin of the posterior portion of temporal region, the auricle and the tympanic membrane. The auriculotemporal nerve also accepts the postganglionic parasympathetic fibers from the otic ganglion that supply the parotid gland.

The *otic ganglion*, **ganglion oticum** resides below the foramen ovale medially from the mandibular nerve that gives the *branches to otic ganglion*, **rami ganglionares ad ganglion oticum** (See 'Parasympathetic nervous system' section).

- the *buccal nerve*, **nervus buccalis** the small sensory nerve that penetrates the buccinator and termi-

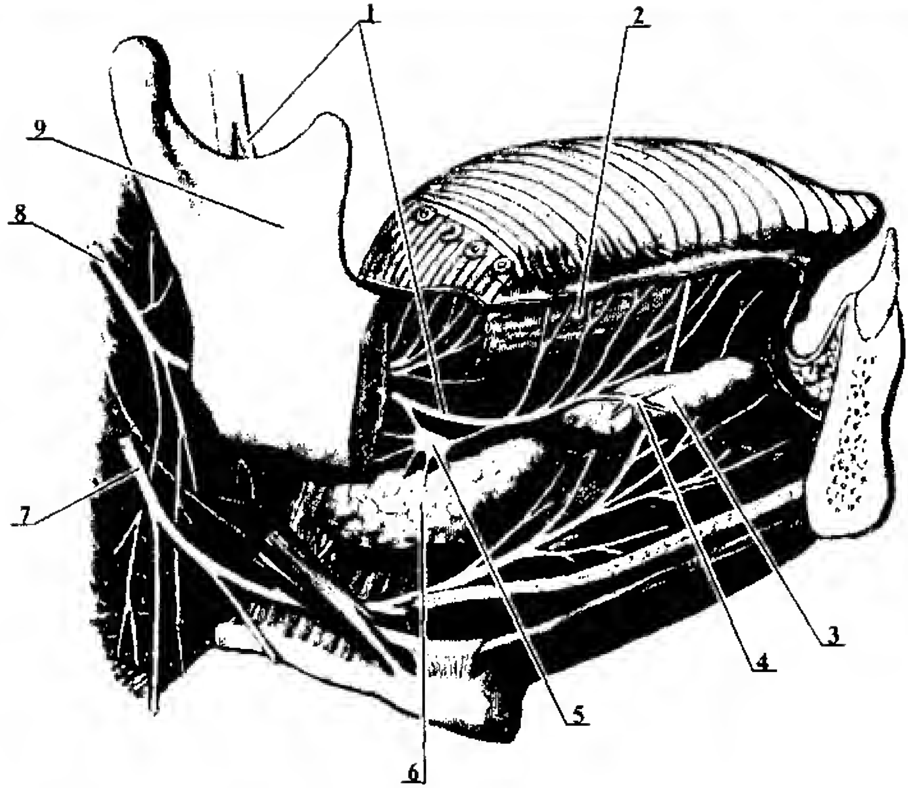


Fig. 33. The nerves of tongue (lateral view). 1 — n. lingualis; 2 – lingua; 3 — gl. sublingualis; 4 — ganglion sublinguale; 5 — ganglion submandibulare; 6 — gl. submandibularis; 7 — n. hypoglossus; 8 — n. glossopharyngeus; 9 — ramus mandibulae.

Anterior $^3/_4$ of tongue is supplied by the lingual nerve (cross-shaded area), the posterior one fourth is supplied by the glossopharyngeal nerve (shaded along).

nates within the buccal mucosa the mucosa of the angle of mouth.

b) The motor branches

The motor branches of the mandibular nerve supply the masticatory muscles. These branches are like the following:

1) the *masseteric nerve,* **nervus massetericus** that supplies the masseter;

2) the *deep temporal nerves,* **nervi temporalis profundi** that supply the temporal muscle;

3) the *nerve to medial pterygoid,* **nervus pterygoideus medialis** that supplies the medial pterygoid;

4) the *nerve to lateral pterygoid,* **nervus pterygoideus lateralis** that supplies the lateral pterygoid respectively.

Apart from the aforesaid fibers, the mandibular nerve supplies the

tensor veli palatini (the *nerve to tensor veli palatini*), and the tensor tympani (the *nerve to tensor tympani*). The inferior alveolar nerve gives the motor fibers (the *nerve to mylohyoid*) to the posterior belly of digastric and the mylohyoid.

Responsibility areas of the trigeminal nerve

Summing up the trigeminal nerve, one may define its responsibility areas:

1) the facial skin above the palpebral fissure (the forehead and the upper eyelid) is under responsibility of the first branch; the facial skin between the palpebral fissure and the oral fissure (the lower eyelid, the upper lip, the nose, the cheeks and the anterior portion of the temporal region) is under responsibility of the second branch; the facial skin below the oral fissure (the chin and the lower lip) together with the posterior portion of temporal region and the auricle is under responsibility of the third branch;

2) the trigeminal nerve provides sensory nerve supply to the nasal mucosa, the mucosa of paranasal sinuses, the oral mucosa, the anterior two thirds of the lingual mucosa and the vascular layer of the eyeball;

3) both upper and lower teeth with related gums feature specific sensory nerve supply;

4) the motor fibers supply the masticatory muscles, several muscles of the oral cavity floor and specifically the tensor veli palatini and the tensor tympani;

5) the cranial dura mater also receives the sensory nerve supply from the trigeminal nerve (except for the posterior cranial fossa);

6) the major cranial glands like the lacrimal gland, the parotid gland, the submandibular gland and the sublingual gland receive targeted sensory nerve supply (from the sensory roots of pertaining parasympathetic ganglia).

Clinical applications

Neuralgia of trigeminal nerve belongs to one of the common disorders. It is manifested as pain attacks without prior external stimulation localized within the respective responsibility areas. Pain sensation arises in the areas of major nerve terminations – around the supraorbital notch, the infraorbital foramen and the mental foramen. One of the possible causes of the state constitutes closing of the cranial openings that pass the principal branches of the nerve.

VI. The abducent nerve, nervus abducens

The abducent nerve is purely motor nerve that supplies one extrinsic muscle of eyeball. The *nucleus of abducens nerve*, **nucleus nervi abducentis** resides within the tegmentum of pons on the level of facial colliculus (dorsally from the genu of facial nerve). The nerve arises from the medullopontine sulcus between the pons and the olives and traverses the cavernous sinus running laterally from the internal carotid artery. The nerve enters the orbit via the inferior orbital

fissure and terminates within the lateral rectus (Fig. 31).

VII. The facial nerve, nervus facialis

The nuclei of the facial nerve

The facial nerve comprises mostly the motor fibers that arise from the *motor nucleus of facial nerve*, **nucleus nervi facialis**. These fibers supply the facial muscles. The nucleus resides within the tegmentum of pons ventrally from the nucleus of abducent nerve somewhat below the *facial colliculus*. The parasympathetic fibers arise from the *superior salivatory nucleus*, **nucleus salivatorius superior**. They supply the lacrimal, the parotid, the submandibular and the sublingual glands. The sensory nucleus is the *nucleus of solitary tract*, **nucleus tractus solitarii** that accepts the central processes of the sensory pseudounipolar cells of the *geniculate ganglion*, **ganglion geniculi**.

Topography

The facial nerve arises from the medullopontine sulcus laterally from the abducent nerve with two roots. The greater root is the facial nerve itself; it comprises the motor fibers. The lesser root is called the intermediate nerve. The *intermediate nerve*, **nervus intermedius**[1] comprises the sensory (gustatory) and the parasympathetic fibers and thus features two nuclei — the *superior salivatory nucleus*, **nucleus salivatorius superior** (the parasympathetic nucleus) and the *nucleus of solitary tract*, **nucleus tractus solitarii** (the sensory nucleus). The two nerves join in the facial area of the internal acoustic meatus.

The part in facial canal

The facial and the intermediate nerves form a single trunk that enters the *facial canal*, **canalis nervi facialis** (Fig. 34). The nerve configures to the facial canal i.e. first it runs anteriorly and laterally to reach the genu of facial canal. At this point, the nerve bends posteriorly to form the *geniculum* (Lat. Id.) and proceeds in posteroinferior direction along the mastoid wall of the tympanic cavity (here the facial canal becomes evident as the prominence of facial canal). Upon passing the tympanic cavity, the nerve runs vertically down to escape via the *stylomastoid foramen*, **foramen stylomastoideum**. The genu of facial canal houses the *geniculate ganglion*, **ganglion geniculi** made up of the sensory pseudounipolar cells. Their central processes enter the brainstem and synapse with the cells of the *nucleus of solitary tract*, while the peripheral processes run to their responsibility areas.

The branches of the part in canal

The part in canal gives off two branches that belong to the intermediate nerve. They are the greater petrosal nerve and the chorda tympani (the *nerve to stapedius* belongs to the facial nerve):

- the *greater petrosal nerve*, **nervus petrosus major** escapes from the

[1] the nerve of Wrisberg also called the XIII pair of the cranial nerves

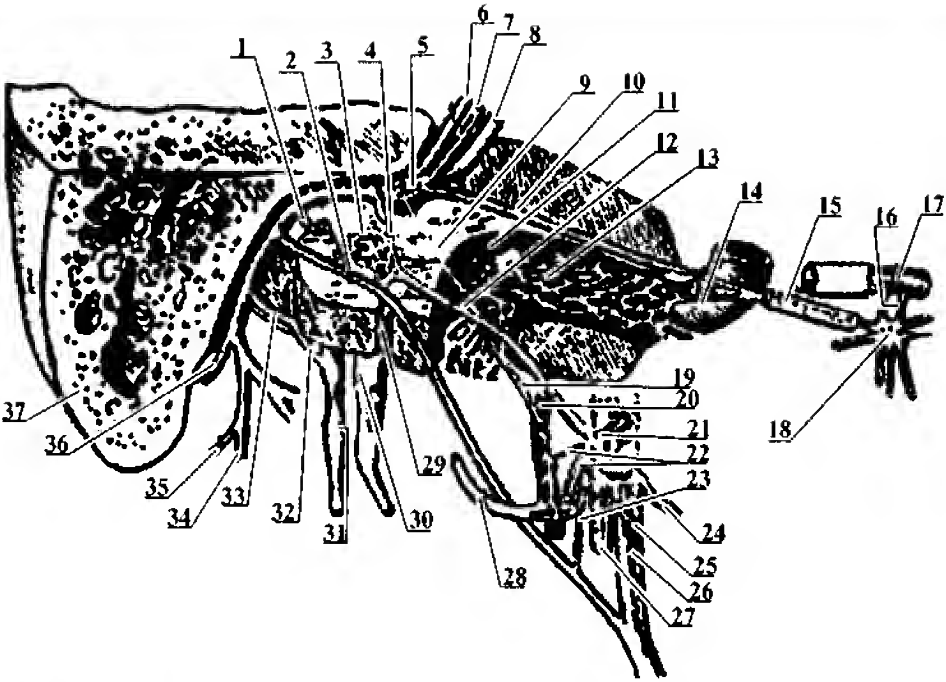


Fig. 34. The nerves in canals of the temporal bone. 1 — n. stapedius; 2 — chorda thympani; 3 — plexus thympanicus; 4 — r. communicans cum plexo thympanico; 5 — ganglion geniculi; 6 — n. facialis; 7 — n. intermedius; 8 — n. vestibulocochlearis; 9, 19 — r. communicans cum plexo a. meningeae mediae; 10 — n. petrosus major; 11 — n. caroticothympanicus; 12 — n. petrosus minor; 13 — plexus caroticus internus; 14 — n. petrosus profundus; 15 — n. canalis pterygoidei; 16 — nn. pterygopalatini; 17 — n. maxillaris; 18 — ganglion pterygopalatinum; 20 — plexus arteriae meningae mediae; 21 — ganglion oticum; 22 — rr. ganglionares ad ganglion oticum; 23 r. communicans cum chorda thympani; 24 — n. massetericus; 25 — n. mandibularis; 26 — n. lingualis; 27 — n. alveolaris inferior; 28 — n. auriculotemporalis; 29 — n. thympanicus; 30 — n. glossopharyngeus; 31 — ganglion superius n. vagi; 32 — r. auricularis n. vagi; 33 — r. communicans cum n. vago; 34 — r. stylohyoideus n. facialis; 35 — r. digastricus; 36 — n. auricularis posterior; 37 — processus mastoideus.

facial canal via the *hiatus for greater petrosal nerve* and runs along the groove of the same name on the anterior surface of the petrous part of temporal bone. The nerve traverses the cartilaginous sealing of the foramen lacerum and becomes evident on the external cranial base. Then, the nerve proceeds to the pterygoid canal where joins the *deep petrosal nerve*, **nervus petrosus profundus** (it arises from the internal carotid plexus). The two nerves form the *nerve of pterygoid canal*, **nervus canalis pterygoidei**[1] that reaches the pterygopalatine

[1] the Vidian nerve

fossa with featured pterygopalatine ganglion. The nerve carries the parasympathetic preganglionic fibers that synapse with the pterygopalatine ganglion cells. The postganglionic fibers further take their routes as follows:

1) the fibers to the nasal cavity join the posterior nasal branches (of the trigeminal nerve); they supply the minor glands of nasal mucosa;

2) the fibers to the palatine mucosa join the respective branches of the maxillary nerve (the palatine nerves); they supply the minor glands of the palatine mucosa;

3) the fibers to the lacrimal gland take quite a complex route. Initially they join the maxillary nerve to reach the inferior orbital fissure. There the fibers pass to the *zygomatic nerve*, which carries them to the lateral wall of the orbit. At that point, the fibers detach from the vehicle and run alone as the *communicating branch with zygomatic nerve* that finally joins the *lacrimal nerve*; the fibers provide secretory nerve supply to the lacrimal gland.

- the *chorda tympani* (Lat. Id.) detaches from the facial nerve in the area of the stylomastoid foramen and enters the *canaliculus for chorda tympani* to return to the tympanic cavity. Arching superiorly, the nerve runs along the medial surface of the tympanic membrane (that gives the name to the nerve) within the mucosa fold. Note that the chorda tympani supplies but nothing within the tympanic cavity and simply proceed to the canaliculus outlet – the *petrotympanic fissure*, **fissura petrotympanica**. The nerve joins the lingual nerve and proceeds to its responsibility area. The chorda tympani contains the preganglionic parasympathetic fibers and the sensory taste fibers from the geniculate ganglion. The preganglionic fibers run to the submandibular and sublingual ganglia to synapse with pertaining cells. The postganglionic fibers provide sensory nerve supply to the respective salivary glands. The sensory taste fibers run within the lingual nerve and supply the lingual papilla of the anterior two thirds of lingual mucosa.

The facial part of the nerve

After escaping from the facial canal, the nerve appears to have only motor fibers. The nerve penetrates the parotid gland where forms the *parotid plexus*, **plexus intraparotideus**. The branches of the plexus fan out and take five routes to responsibility areas. These branches supply the mimic muscles (Fig. 35):

- the *temporal branches*, **rami temporales** terminate at the temporal region and supply the muscles of forehead and the orbicularis oculi;
- the *zygomatic branches*, **rami zygomatici** supply the orbicularis oculi and both zygomatic muscles;
- the *buccal branches*, **rami buccales** supply the buccinators and the muscles related to the mouth and the nose;
- the *marginal mandibular branch*, **ramus marginalis mandibulae**

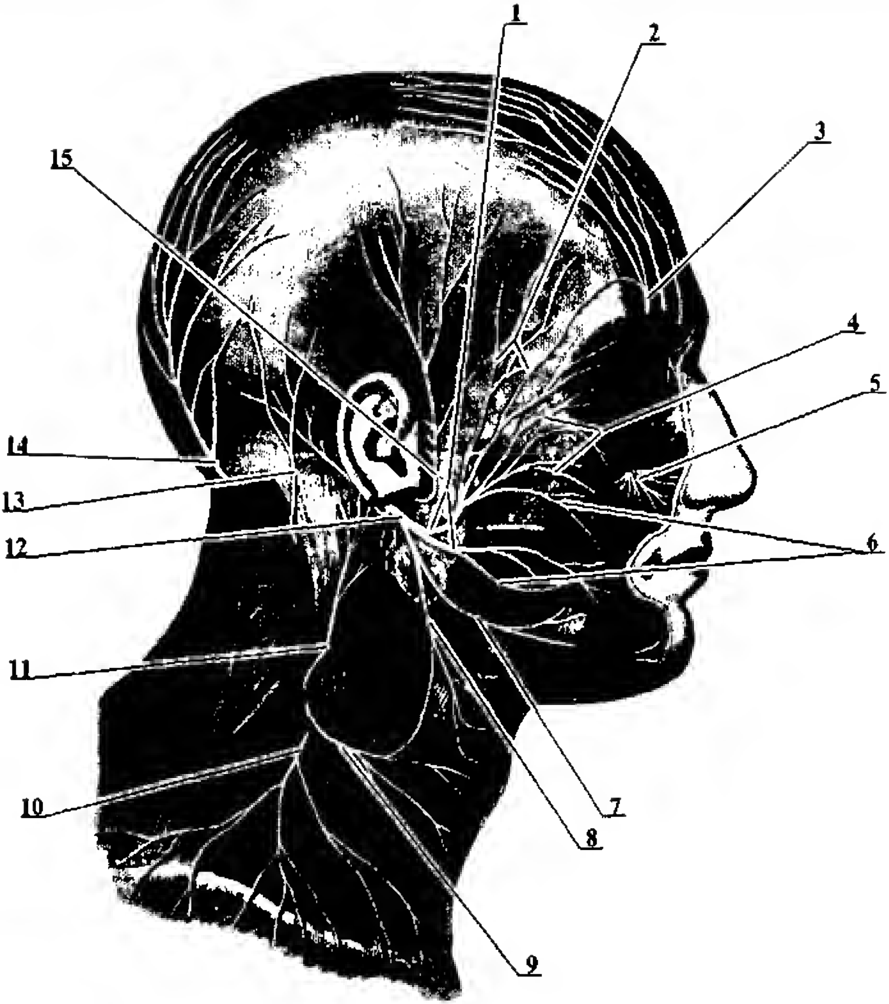


Fig. 35. The superficial nerves of head and neck. 1 – plexus intraparotideus; 2 – rr. temporales; 3 – n. supraorbitalis; 4 – rr. zygomatici; 5 – n. infraorbitalis; 6 – rr. buccales; 7 – r. marginalis mandibularis; 8 – r. colli; 9 – n. transverses colli; 10 – nn. supraclaviculares; 11 – n. auricularis magnus; 12 – n. facialis; 13 – n. occipitalis minor; 14 – n. occipitalis major; 15 – n. auriculotemporalis.

runs along the base of mandible to the mental and the oral muscles;

- the *cervical branch*, **ramus colli** descends to the cervical region. It supplies the platysma.

Apart from the branches listed, the facial nerve gives the branches to the auricular muscles, to the occipital belly of epicranius, to the posterior belly of digastric and to the stylohyoid.

Clinical applications

Conductivity disorders in the facial nerve result in paralysis of the facial muscles. This may be caused by chilling that develops into neuritis. The state is manifested by facial asymmetry. The central paralysis results from brain hemorrhages. Facial nerve disorders may also manifest as taste acuity loss or impaired secretion of the lacrimal and the salivary glands.

VIII. The vestibulocochlear nerve, nervus vestibulocochleais

The vestibulocochlear nerve is the nerve of specific sensitivity. It comprises two purely sensory nerves that carry the impulses from two different sources:

- the *vestibular nerve*, **nervus vestibularis** arises from the sensory bipolar cells of the *vestibular ganglion*, **ganglion vestibulare** situated on the floor of the internal acoustic meatus;
- the *cochlear nerve*, **nervus cochlearis** arises from the sensory bipolar cells of the *spiral ganglion*, **ganglion spirale cochleae** situated within the spiral canal of cochlea.

Both nerves join within the internal acoustic opening to form one vestibulocochlear nerve that arises from the *internal acoustic opening* and enters the brainstem through the medullopontine sulcus (in the area between the pons, the medulla oblongata and the cerebellum, laterally from the facial nerve).

The nuclei of the vestibulocochlear nerve

The vestibular nerve features four nuclei — the superior, the inferior, the lateral and the medial. The cochlear nerve features the anterior (ventral) and the posterior (dorsal) nuclei. The nuclei reside within the tegmentum of pons at level of the vestibular area of the rhomboid fossa.

The *vestibular nerve*, nervus vestibularis

The pertaining receptors occupy the maculae of utricle and saccule and the ampullary crests of the semicircular ducts. The receptor cells synapse with the peripheral processes of sensory bipolar cells of the *vestibular ganglion*, **ganglion vestibulare** situated on the floor of the internal acoustic meatus. The central processes of the cells merge into the vestibular nerve that arises from the internal acoustic opening and enters the brainstem in the respective area. The fibers within the brain split into the ascending and the descending bundles that synapse with the vestibular nuclei. The axons of the nuclei maintain communications with the fastigial nuclei of cerebellum via the *vestibulocerebellar fibers* and with the spinal cord via the *vestibulospinal tract*. Some fibers also join the *medial longitudinal fasciculus*

(formed of the axons of nuclei of the III, IV and VI cranial nerves).

Impairments of the vestibular pathways result in disorders of equilibrium and movements coordination.

The *cochlear nerve*, **nervus cochlearis**

The receptor set for the nerve forms the *spiral organ*, **organum spirale** (the organ of Corti). The receptor cells synapse with the peripheral processes of sensory bipolar cells of the spiral ganglion that resides within the spiral canal of cochlea.

The central processes of the ganglion cells form the cochlear nerve that runs together with the vestibular nerve. The nerve enters the brainstem at the cerebellopontine angle and terminates within the related nuclei. The axons from the anterior nucleus decussate and become evident as the *trapezoid body*, **corpus trapezoideum**. The axons from the posterior nucleus also decussate and become evident in the rhomboid fossa as the *medullary stria of fourth ventricle*. On reaching the median sulcus of rhomboid fossa, the fibers enter deep into the brainstem tissue and join the trapezoid body. Upon crossing, the fibers loop laterally to give rise to the *lateral lemniscus*, **leinscus lateralis** (the auditory lemniscus). The lemniscus ascends to the subcortical auditory centers (the fibers become temporarily evident as the *trigone of lateral lemniscus*) situated within the medial geniculate bodies and the inferior colliculi of the tectal plate. The medial geniculate body gives rise to the auditory pathway that passes through the posterior limb of the internal capsule and terminates within the cortex of the superior temporal gyrus (namely within the transverse temporal gyri -- the Heshl's gyri). The analyzer is responsible for the end-point analysis of the auditory impulses.

The axons from the inferior colliculi join the tectospinal tract responsible for 'start reflex' – the instant response to sudden sound stimuli.

IX. The glossopharyngeal nerve, nervus glossopharyngeus

The glossopharyngeal nerve is the mixed-type nerve.

The nuclei of the glossopharyngeal nerve

The glossopharyngeal nerve comprises the motor, the sensory and the autonomic fibers that arise from three respective nuclei situated within the medulla oblongata. The motor fibers arise from the *nucleus ambiguus* (Lat. Id.), the sensory fibers terminate within the *nucleus of solitary tract*, **nucleus tractus solitarii** and the autonomic fibers arise from the *inferior salivatory nucleus*, **nucleus salivatorius inferior.**

Topography of the nerve

The nerve arises as numerous rootlets from the posterolateral sulcus of the medulla oblongata right behind the inferior olive. It escapes from the cranial cavity via the anterior portion of the jugular foramen and proceeds to the cervical region. There the nerve loops around the internal carotid artery and the stylopharyngeus and

proceeds to the root of tongue where it splits into the terminal branches – the *lingual branches*, **rami linguales** (Fig. 33, 36). The nerve features two ganglia – the *superior ganglion*, **ganglion superius** situated in the area of the jugular foramen and the *inferior ganglion*, **ganglion inferius** situated right below the outlet of the foramen. Both ganglia comprise the sensory pseudounipolar cells. Their central processes run to the nucleus of solitary tract and the peripheral processes join the branches of the nerve and proceed to responsibility areas (the pharyngeal mucosa, the tympanic mucosa, the posterior third of the tongue and the carotid sinus).

The branches of the glossopharyngeal nerve:

- the *tympanic nerve*, **nervus tympanicus** comprises the sensory and the parasympathetic fibers. It arises from the inferior ganglion and enters the tympanic cavity via the *tympanic canaliculus* where it leaves all sensory fibers to form the *tympanic plexus*, **plexus tympanicus**. The plexus supplies the tympanic mucosa, the mastoid air cells mucosa and the auditory tube mucosa. The autonomic fibers proceed to the *hiatus for lesser petrosal nerve* where they form the *lesser petrosal nerve*, **nervus petrosus minor**. This purely parasympathetic nerve runs along the groove for lesser petrosal nerve and escapes from the cranial cavity via the *sphenopetrosal fissure*, **fissura sphenopetrosa**. Upon reaching the inferior cranial base, the nerve enters the *otic ganglion*, **ganglion oticum** associated with the mandibular nerve. The postganglionic fibers join the auriculotemporal nerve and proceed to the parotid gland;
- the *lingual branches*, **rami linguales** run to the posterior third of lingual mucosa. The nerve comprises the fibers of general sensitivity and the gustatory fibers that supply the taste buds of the *vallate papillae*;
- the *pharyngeal branches*, **rami pharyngei** participate in formation of the pharyngeal plexus; these fibers provide sensory nerve supply to the pharyngeal mucosa;
- the *stylopharyngeal branch*, **ramus musculi stylopharyngei** is the motor branch to the stylopharyngeus;
- the *tonsillar branches*, **rami tonsillares** supply the mucosa of the palatine tonsils and the related arches;
- the *carotid branch*, **ramus sinus carotici** runs to the carotid sinus and the carotid body. This branch conducts the impulses from the carotid sinus to the medulla oblongata participating thus in regulation of the blood pressure and heart rate.

X. The vagus nerve, nervus vagus

The vagus nerve is the principal parasympathetic nerve of the human body that supplies the cervical, the thoracic and the abdominal viscera (except for the lesser pelvis viscera). The vagus nerve comprises numerous visceral sensory fibers that conduct the impulses from the related viscera. It also features the motor fibers that

supply the striated muscles of the upper portions of the alimentary and the respiratory tracts.

The nuclei of the vagus nerve

The largest nucleus of the vagus nerve is the *dorsal nucleus of vagus nerve*, **nucleus dorsalis nervi vagi** that gives rise to the autonomic fibers. It resides within the medulla oblongata at level of the *vagal trigone*, **trigonum nervi vagi**.

The motor fibers arise from the *nucleus ambiguus* (Lat. Id.) and the sensory fibers (the fibers that conduct interoceptive sensitivity fibers and the taste fibers) terminate within the *nucleus of solitary tract*, **nucleus tractus solitarii**. The exteroceptive sensitivity fibers from the skin and the mucous membranes terminate within the inferior portion of the *spinal nucleus of trigeminal nerve*. The vagus nerve has a wide responsibility area so it is subdivided into the cranial, the cervical, the thoracic and the abdominal parts.

The cranial part
(between the origination point and the superior ganglion)

Topography of the nerve

The vagus nerve arises with 10-15 rootlets from the posterolateral sulcus of the medulla oblongata posterior to the inferior olive (right below the glossopharyngeal nerve). The rootlets merge into a single trunk that escapes from the cranial cavity via the *jugular foramen*, **foramen jugulare**.

The cranial part gives the *meningeal branch*, **ramus meningeus** to the dura mater of the posterior cranial fossa and the *auricular branch*, **ramus auricularis**. The auricular branch enters the *mastoid canaliculus*, **canaliculus mastoideus** that gives escape to the nerve via the tympanomastoid fissure posterior to the auricle. The branch supplies the skin of the auricle and the skin of the posterior wall of the external acoustic meatus.

The ganglia of the nerve

The vagus nerve features two ganglia much alike those of the glossopharyngeal nerve. The *superior ganglion*, **ganglion superius** resides in the area of the jugular foramen and the *inferior ganglion*, **ganglion inferius** resides right below the jugular foramen opening. Both ganglia comprise the sensory pseudounipolar cells. The superior ganglion is responsible for exteroceptive sensitivity while the inferior ganglion is responsible for visceral (interoceptive) sensitivity.

The cervical part
(between the inferior ganglion and the recurrent laryngeal nerve)

Topography of the cervical part

In the beginning of its way, the cervical part runs between the internal carotid artery and the internal jugular vein. Below the carotid sinus, the nerve runs between the common carotid artery and the internal jugular vein. The greater cervical vessels and the vagus nerve constitute one neurovascular bundle enfolded into the carotid sheath (Fig. 36). Upon entering the thoracic inlet, the right nerve passes between the subclavian artery

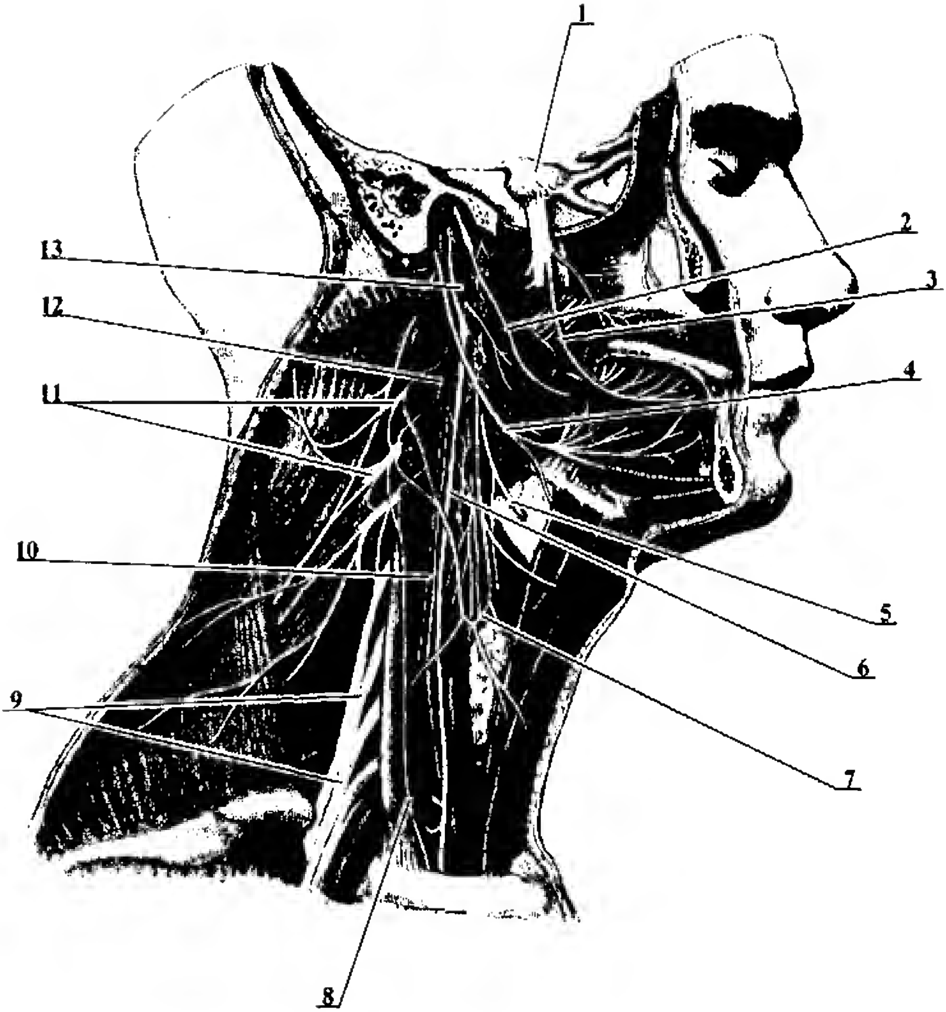


Fig. 36. The nerves of head and neck, lateral view. 1 — gangl. trigeminale; 2 — n. glossopharyngeus; 3 — n. lingualis; 4 — n. hypoglossus; 5 — n. laryngeus superior; 6 — n. vagus; 7 — ansa cervicalis; 8 — n. phrenicus; 9 — plexus brachialis; 10 — truncus sympathicus; 11 — plexus cervicalis; 12 — gangl. cervicale superius; 13 — gangl. inferius n. vagi.

and the subclavian vein; the left nerve passes between the common carotid artery and the subclavian artery and proceeds onto the anterior surface of the aortic arch.

The branches of the cervical part

The cervical part gives the branches as follows:

- the *pharyngeal branch*, **ramus pharyngeus** participates in formation of the pharyngeal plexus together with the respective branch of the glossopharyngeal nerve and some sympathetic branches. The plexus supplies the pharyngeal muscles, the pharyngeal mucosa and the muscles of the soft palate (except for the *tensor veli palatini*);
- the *superior laryngeal nerve*, **nervus laryngeus superior** arises from the inferior ganglion. The nerve descends to the hyoid bone and where splits into two branches – the *external branch*, **ramus externus** and the *internal branch*, **ramus internus**. The external (motor) branch supplies *only* the cricothyroid and the internal branch (it comprises the sensory and the parasympathetic fibers) supplies the epiglottic mucosa, the laryngeal mucosa above the rima glottidis and the mucosa of the root of tongue (partially). The superior laryngeal nerve also comprises the gustatory fibers that run from the taste buds of the root of tongue and the epiglottis;
- the *superior cervical cardiac branches*, **rami cardiaci cervicales superiores** descend along each common carotid artery and joins the *cardiac plexus*, **plexus cardiacus**. These branches carry only the parasympathetic preganglionic fibers from the dorsal nucleus of vagus nerve. The fibers reach synapse within the ganglia of the cardiac plexus. The cardiac branches also feature the interoceptive sensory fibers that participate in regulation of blood pressure;
- the *recurrent laryngeal nerve*, **nervu laryngeus recurrens** arises within the upper portion of the thoracic cavity yet its branches terminate in the cervical region. The left nerve loops around the aortic arch, the right nerve loops around the subclavian artery. Both nerves return to the cervical region where they reside between the trachea and the esophagus. The nerve comprises all types of fibers and supplies the trachea (the *tracheal branches*, **rami tracheales**), the esophagus (the *esophageal branches*, **rami oesophageales**), *all* laryngeal muscles (except for the cricothyroid) and the laryngeal mucosa below the rima glottidis. The laryngeal nerves also supply the thyroid gland with the sensory and the secretory nerve fibers;
- the *inferior cervical cardiac branches*, **rami cardiaci cervicales inferiors** may arise either from the recurrent laryngeal nerves or directly from the vagus nerves on each side. They carry the sensory and the preganglionic parasympathetic fibers to the cardiac plexus.

Clinical applications

The recurrent laryngeal nerve runs posterior to the lobes of the thyroid gland, which becomes a concern in thyroid gland surgery. Injury to the recurrent laryngeal nerve results in aphonia because of laryngeal muscles paralysis.

The thoracic part of the vagus nerve

(between the recurrent laryngeal nerve and the esophageal hiatus of the diaphragm)

Topography of the thoracic part

Within the thoracic cavity, the right vagus nerve runs anterior to the subclavian artery while the left nerve runs anterior to the aortic arch. Both nerves then bypass the roots of lungs posteriorly and enter the posterior mediastinum where they run along the esophagus. The left nerve passes onto the anterior surface of the esophagus and the right – on the posterior surface. The nerves branch off within the wall of the esophagus thus forming the *esophageal plexus*, **plexus oesophagealis**. The lower portion of the plexus gives rise to the *anterior* and the *posterior vagal trunks*, **trunci vagales anterior et posterior** that enter the abdominal cavity via the *esophageal hiatus* (Fig. 37).

The branches of the thoracic part

Within the thoracic cavity, the nerve gives the following branches:

- the *tracheal branches*, **rami tracheales** that form the tracheal plexus (together with the sympathetic fibers);
- the *thoracic cardiac branches*, **rami cardiac thoracici** comprise the sensory and the parasympathetic fibers that join the cardiac plexus;
- the *bronchial branches*, **rami bronchiales** run to the bronchi to form the *pulmonary plexus*, **plexus pulmonalis** together with the sympathetic fibers. These branches also contain the visceral sensory fibers that supply the bronchial mucosa;
- the *oesophageal plexus*, **plexus esophagealis** arises from the branches of both nerves and from the visceral branches of the thoracic compartment of the sympathetic trunk.

The abdominal part

(between the esophageal hiatus and the sigmoid colon)

Topography of the abdominal part

Upon reaching the abdominal cavity, the anterior vagal trunk branches within the anterior wall of stomach. The posterior vagal trunk branches within the posterior wall of stomach and finally joins the coeliac plexus. The parasympathetic fibers of the vagus nerve reach the viscera along the related arteries and form the autonomic plexuses together with the sympathetic fibers. The branches of the vagus nerve contain numerous visceral sensory fibers that supply the respective abdominal viscera.

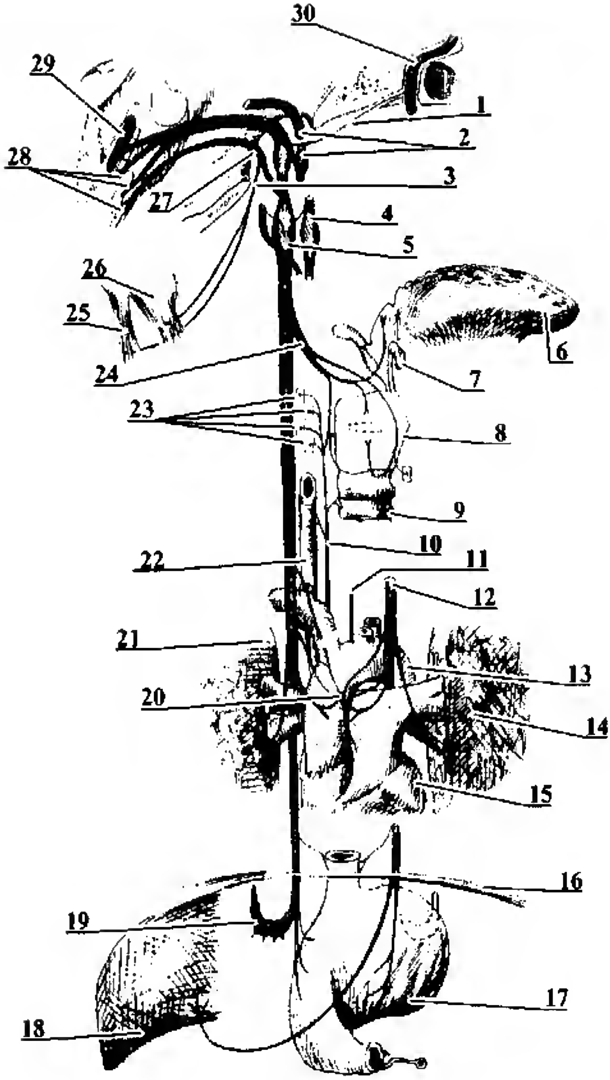


Fig. 37. The vagus and the hypoglossal nerves. 1 — r. communicans cum nervo faciale; 2 — n. glossopharyngeus; 3 — n. accessorius; 4 — r. communicans cum nervo hypoglosso; 5 — r. communicans cum trunco sympathico; 6 — lingua; 7 — os hyoideum; 8 — larynx; 9 — trachea; 10 — n. laryngeus reccurens dexter; 11 — n. laryngeus reccurens sinister; 12 — n. vagus sinister; 13 — arcus aortae; 14 — pulmo sinister; 15 — cor; 16 — m. phrenicus; 17 — gaster; 18 — hepar; 19 — ganglion coeliacum dexter; 20 — ganglion cardiacus; 21 — pulmo dexter; 22 — oesophagus; 23 — rr. n. laryngeus inferior dexter; 24 — n. laryngeus superior; 25 — m. trapezius; 26 — m. sternocleidomastoideus; 27 — n. accessorius; 28 — nuclei n. vagi et n. accessorii; 29 — n. dorsalis n. vagi; 30 — n. facialis.

The branches of the abdominal part

Within the abdominal cavity, the vagus nerve gives the branches as follows:

- the *anterior gastric branches*, **rami gastrici anteriores** arise from the anterior trunk and run along the lesser curvature of stomach to reach its anterior wall;
- the *hepatic branches*, **rami hepatici** also arise from the anterior trunk and run along the common hepatic artery to reach the liver. The branches run between the layers of the lesser omentum;
- the *posterior gastric branches*, **rami gastrici posteriors** arise from the posterior trunk and run along the lesser curvature of stomach to reach its posterior wall;
- the *renal branches*, **rami renales** and run along the renal arteries to reach the kidneys;
- the *coeliac branches*, **rami coeliaci** are the last branches of the group. They join the coeliac plexus yet never synapse within its ganglia. The fibers spread along the arteries and reach the spleen, the pancreas, the small and the large intestines (up to the sigmoid colon). The parasympathetic fibers synapse within the intramural ganglia of the respective viscera.

Clinical applications

Bilateral destruction of the vagus nerve is fatal while unilateral partial lesion may result in deranged deglutition and phonation because of paralyzed palatine, pharyngeal and laryngeal muscles. The state may be accompanied by various autonomic disorders related to cardiac activities, respiration, digestion etc.

XI. The accessory nerve, nervus accessorius

The accessory nerve comprises only motor fibers that arise from two nuclei:

1 – the *nucleus ambiguus* (Lat. Id.) resides within the medulla oblongata. The fibers of the accessory nerve arise from the caudal portion of the nucleus. The rest is shared by the IX and the X pairs;

2 – *nucleus of accessory nerve*, **nucleus nervi accessorii** resides within the posterolateral portion of the anterior grey column of the spinal cord. The nucleus occupies the segments C1 through C6.

The fibers from the nucleus ambiguus take a short route within the accessory nerve and then detach to join the vagus nerve. Within the vagus nerve, they run as the superior laryngeal nerve. The spinal fibers supply the trapezius and the sternocleidomastoid.

Topography of the nerve and related branches

The accessory nerve features the cranial roots and the spinal roots:

- the *spinal roots*, **radices spinales** arise from the spinal cord between the anterior and the posterior roots and merge into a single trunk, which ascends to the cranial cavity and joins the cranial roots;
- the *cranial roots*, **radices craniales** arise from the posterolateral sulcus

of the medulla oblongata posterior to the inferior olive. Both cranial and spinal roots merge into one *trunk of accessory nerve*, **truncus nervi accessorii**, which escapes from the cranial cavity via the jugular foramen and proceeds to the cervical region. Within the cervical region, the nerve splits into the *external branch*, **ramus externus** and the *internal branch*, **ramus internus**. The internal branch comprises the fibers from the nucleus ambiguus that join the vagus nerve. The external branch, which is the accessory branch itself, supplies the trapezius and the sternocleidomastoid.

XII. The hypoglossal nerve, nervus hypoglossus

The hypoglossal nerve comprises the motor fibers to the lingual muscles. The fibers arise from the *nucleus of hypoglossal nerve*, **nucleus nervi hypoglossi** situated within the medulla oblongata at level of the hypoglossal trigone. The nerve arises from the brainstem as numerous rootlets that join into a single trunk. The nerve escapes from the cranial cavity via the *hypoglossal canal*, **canalis nervi hypoglossi** and reaches the cervical region. Upon reaching the tongue, the nerve branches off to give the *lingual branches*, **rami linguales** that supply all muscles of tongue (Fig. 33, 36). The hypoglossal nerve also gives the *descending branch*, **ramus descendens** that comprises the motor fibers from the first spinal nerve. The branch anastomoses with the branches of the cervical plexus to form the *ansa cervicalis* (Lat. Id.). The ansa supplies the infrahyoid muscles of neck (the *sternohyoid*, the *sternothyroid*, the *thyrohyoid* and the *omohyoid*).

Clinical applications

Unilateral injury to the hypoglossal nerve results in paralysis of the lingual muscles on the respective side with further atrophy. Bilateral injury results in complete immobility of the tongue accompanied by deranged speech, deglutition and mastication.

Practice questions

1. Name all tunics of the nerve.
2. Describe internal structure of the nerve.
3. What features of the nerve allow its stretching?
4. What are the features of myelinated and non-myelinated fibers?
5. What features allow distinguishing the sensory, the motor and the mixed nerves?
6. Describe the ganglia of the nervous system.
7. Discuss classification of the ganglia.
8. Name all pairs of the cranial nerves.
9. Discuss classification of the cranial nerves by fibers contents.
10. Discuss classification of the cranial nerves by origin.
11. Describe origination, formation and topography of the I cranial nerves.

12. Describe origination, formation and topography of the II cranial nerves.
13. Describe the III cranial nerves including their origination, the general features, the featured nuclei, the point of arise, the escape point, the related branches and the responsibility areas.
14. Describe the IV cranial nerves including their origination, the general features, the nucleus, the point of arise, the escape point and the responsibility areas.
15. Describe the V pair of cranial nerve including origination, the general features and intracranial part of the nerve.
16. Describe the sensory ganglion of the V cranial nerve with related topography and fibers.
17. Describe the first branch of the V cranial nerve including formation, escape point, the related branches and responsibility areas.
18. Describe the second branch of the V cranial nerve including formation, escape point, the related branches and responsibility areas.
19. Describe the third branch of the V cranial nerve including formation, escape point, the related branches and responsibility areas.
20. Describe the VI cranial nerves including their origination, the general features, the nucleus, the point of arise, the escape point and the responsibility areas.
21. Describe the VII cranial nerves (with the intermediate nerve) including their origination, the general features, the related nuclei, the point of arise, the escape point and the responsibility areas.
22. Describe the VIII cranial nerves including their origination, the general features, the nuclei, topography of the nerves and the responsibility areas.
23. Describe the IX cranial nerves including their origination, the general features, the featured nuclei, the point of arise, the escape point and the responsibility areas.
24. Describe the X cranial nerves including their origination, the general features, the nucleus, the point of arise, the escape point, the parts and the responsibility areas.
25. Describe the cranial and the cervical parts of the X cranial nerve including topography, the fibers and responsibility areas.
26. Describe the cervical and the thoracic parts of the X cranial nerve including topography, the fibers and responsibility areas.
27. Describe the XI cranial nerves including their origination, the general features, the nuclei, the point of arise, the escape point and the responsibility areas.
28. Describe the XII cranial nerves including their origination, the general features, the nuclei, the point of arise, the escape point and the responsibility areas.

THE SPINAL NERVES, NERVI SPINALES

The spinal cord gives rise to 31 pair of the spinal nerves. These nerves are like the following:

8 pairs of the *cervical nerves,* **nervi cervicales** (C1 – C8);

12 pairs of the *thoracic nerves,* **nervi thoracici** (Th1 – Th12);

5 pairs of the *lumbar nerves,* **nervi lumbales** (L1 – L5);

5 pairs of the *sacral nerves,* **nervi sacrales** (S1 – S5);

1 *coccygeal nerves,* **nervus coccygeus** (Co1).

Formation of the spinal nerve

Each spinal nerve arises in the area of the intervertebral foramen as the result of merging of the anterior and the posterior roots of the spinal cord (Fig. 5):

- the *anterior (ventral) root,* **radix anterior (ventralis)** comprises the motor fibers that arise from the motor nuclei of the anterior grey columns. The roots of the segments C8 through L2 also comprise the autonomic (sympathetic) fibers that arise from the sympathetic nuclei of the lateral grey columns;
- the *posterior (dorsal) root,* **radix posterior (dorsalis)** comprises the sensory fibers represented with the central processes of the sensory pseudounipolar cells of the *spinal ganglia,* **ganglia spinales**. The fibers run to respective relay centers of the spinal cord and the medulla oblongata. The peripheral processes of the cells join the spinal nerves and run to the respective receptors.

(Note: the posterior roots actually take but little part in formation of the spinal nerve. It would be more correct to say that the spinal nerve comprises the fibers of the anterior roots and the *peripheral processes* of the sensory pseudounipolar neurons of the spinal ganglia. The posterior roots were included for convenience reason.)

Typical divisions of the spinal nerve

The principal *trunk of spinal nerve,* **truncus nervi spinalis** (approx. 1 cm long) escapes from the intervertebral foramen and gives rise to four branches – the anterior ramus, the posterior ramus, the meningeal branch and so called ramus communicans. The latter is present in the nerves C8 through L2:

- the *anterior (ventral) rami,* **rami anteriores (ventrales)** are the mixed branches that supply the ventral areas of the neck, the trunk and the limbs. All anterior branches except for those of the thoracic nerves form the plexuses;
- the *posterior (dorsal) rami,* **rami posteriores (dorsales)** also mixed thin branches, they run posteriorly to supply the skin and

the proper muscles of back. The posterior branch of the first spinal nerve comprises only the motor fibers;

- the *rami communicantes* (Lat. Id.) associate the spinal nerves with the sympathetic trunk and thus are present in the nerves C8 through L2. They sometimes referred to as the *white rami communicantes* (called so because of whitish color). The rami communicantes albi comprise the sympathetic preganglionic fibers that arise from the intermediolateral nucleus and reach the ganglia of the sympathetic trunk to synapse with pertaining neurons. The postganglionic fibers from the sympathetic trunk return to the spinal nerve as the *grey rami communicantes* (also called so because of color) that join the anterior and the posterior rami together with the meningeal branches;
- the *meningeal branch*, **ramus meningeus** returns to the vertebral canal to supply the spinal meninges.

Clinical applications

Inflammatory processes, toxic lesions and injury sequelae are known under common term 'neuritis'. The state manifests itself as painful sensation in the affected area (mostly in the lumbar and the sacral regions).

THE POSTERIOR RAMI OF THE SPINAL NERVES

The posterior rami detach from the respective spinal nerve and pass between the spinal processes of the neighboring vertebrae. Within the destination point, the nerves split into the medial and the lateral branches that supply the skin of the dorsal area of the trunk from back of the head down to the gluteal regions, the occipital muscles and the proper muscles of back.

Few posterior rami have proper names:

- the *suboccipital nerve*, **nervus suboccipitalis** is a purely motor posterior branch of the first cervical nerve. It supplies the *suboccipital muscles* and the *semispinalis capitis*;
- the *greater occipital nerve*, **nervus occipitalis major** is a mixed posterior branch of the second cervical nerve. It supplies the skin of the occipital region and the posterior cervical muscles like the splenius capitis, the splenius cervicis, the semispinalis capitis and the longissimus capitis (Fig. 35);
- the *superior cluneal nerves*, **nervi clunium superiores** are the posterior branches of the lumbar and the sacral nerves. They supply the skin of the gluteal region.

THE ANTERIOR RAMI OF THE SPINAL NERVES

The anterior rami of the spinal nerves are much thicker and longer than the posterior rami. They form the plexuses (except for the thoracic nerves) where the nerves interlace and allow fibers swap. The plexuses arise as the result of complex development of the limbs. Four known nervous plexuses are the cervical plexus, the thoracic plexus, the lumbar plexus and the sacral plexus. The last two have no clear demarcation line and may join into one *lumbosacral plexus*, **plexux lumbosacralis.**

THE CERVICAL PLEXUS, PLEXUS CERVICALIS (C1 – C4)

The cervical plexus arises from anterior branches of four upper cervical nerves (C1 – C4). It lies on the deep cervical muscles anterior to the transverse processes of cervical vertebrae, below the sternocleidomastoid (Fig. 36). The plexus gives rise to the sensory, the motor and the mixed branches.

The **cutaneous** (sensory) branches from under the posterior margin of the sternocleidomastoid:

- the *lesser occipital nerve*, **nervus occipitalis minor** ascends to the skin of the occipital region;
- the *great auricular nerve*, **nervus auricularis magnus** ascend along the sternocleidomastoid to the auricle and the external acoustic opening;
- the *transverse cervical nerve*, **nervus transversus colli** runs transversely to the anterior and lateral cervical areas;
- the *supraclavicular nerves*, **nervi supraclaviculares** descend to the upper thoracic regions and shoulder along the lateral cervical triangle. On the way to destination point, the nerves cross the clavicle.

The *ansa cervicalis* (Lat. Id.) is a purely motor branch. It is formed of the superior and the inferior roots. The superior root arises from the hypoglossal nerve yet it constitutes the motor fibers from the C1. The inferior root arises from the cervical plexus (C2 – C3) and joins the superior root thus forming the ansa. It resides anterior to the internal jugular vein below the sternocleidomastoid. The ansa gives off some branches to the infrahyoid muscles (the *sternohyoid*, the *sternothyroid*, the *thyrohyoid* and the *omohyoid*).

The **muscular** (motor) branches supply the deep cervical muscles like the *longus colli*, the *longus capitis*, the *scaleni muscles*, the *rectus capitis anterior* and the *rectus capitis lateralis* and the *levator scapulae*.

The *phrenic nerve*, **nervus phrenicus** is the greatest nerve of the cervical plexus and the sole mixed-type nerve of the group. It runs downwards along the *anterior scalene*, **musculuus scalenus anterior** to reach the thoracic

cavity. The right nerve enters the thoracic inlet between the subclavian artery and the subclavian vein and runs further on anterior to the root of lung between the respective pleura and the pericardium. The left nerve enters the thoracic inlet posterior to the subclavian vein along the subclavian artery. The nerve crosses the aortic arch and proceeds anteriorly and leftwards along the pericardium to reach the respective portion of the diaphragm. The motor branches terminate within the diaphragm to provide motor nerve supply to the muscle (C3 – C5).

The phrenic nerve also comprises the sensory fibers to the pleura and the pericardium – the *pericardial branch*, **ramus pericardiacus**. The sensory *phrenico-abdominal branches*, **rami phrenicoabdominales** penetrate the diaphragm to supply the related peritoneum. The sensory branches of the right phrenic nerve traverse the coeliac plexus and reach the liver; they provide sensory nerve supply to the peritoneal investment and the fibrous capsule of liver.

Clinical applications

Some liver diseases may result in painful sensations along the right phrenic nerve. The pain in this case expands onto the cervical region and concentrates between the crura of the sternocleidomastoid (thus providing easily distinguishable 'phrenicus-symptom'). The phrenic nerve is a vital nerve that sets the diaphragm to motion. The nuclei of the phrenic nerve reside within the anterior grey columns of the segments C3 through C6. Injury to the nuclei or to the nerves may result in diaphragm paralysis.

THE BRACHIAL PLEXUS, PLEXUS BRACHIALIS (C5 – C8 and Th1)

The brachial plexus arises from anterior branches of four lower cervical nerves (C4 – C8) and greater portion of the anterior branch of the first thoracic nerve (Th1).

Topography of the brachial plexus

The brachial plexus features the supraclavicular and the infraclavicular parts (Fig. 38).

1) the *supraclavicular part*, **pars supraclavicularis** appears as three trunks that pass between the anterior and the middle scaleni muscles. The trunks are the *superior trunk*, **truncus superior**, the *middle trunk*, **truncus medius** and the *inferior trunk*, **truncus inferior**;

2) the *infraclavicular part*, **pars infraclavicularis** is the part situated within the axillary fossa where the trunks regroup into the *cords*, **faciculi** that surround the brachial artery. The cords are as follows:

- the *lateral cord*, **fasciculus lateralis** runs laterally along the artery;
- the *medial cord*, **fasciculus medialis** runs medially along the artery;
- the *posterior cord*, **fasciculus posterior** runs posteriorly along the artery.

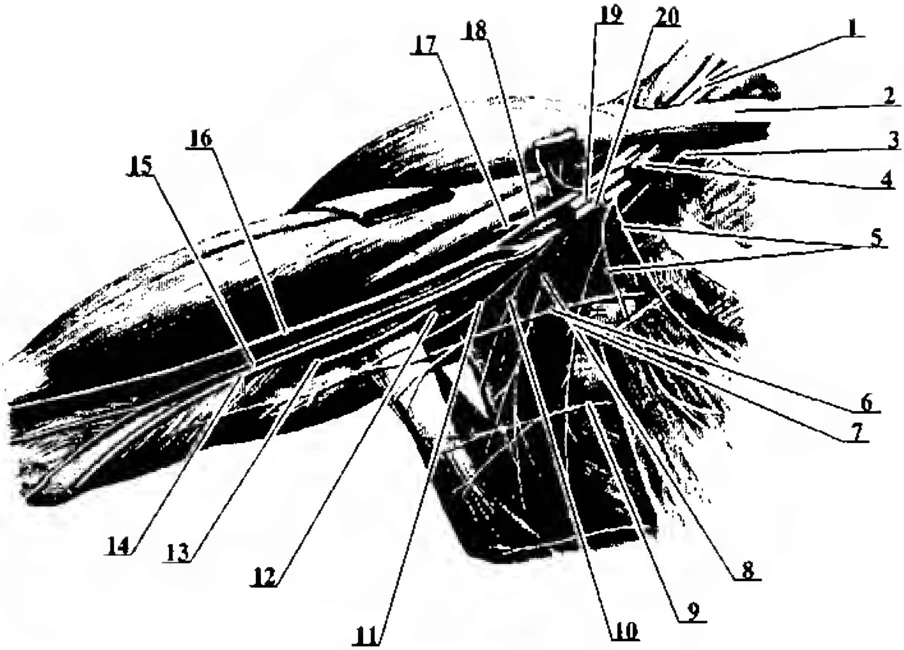


Fig. 38. The nerves of brachial plexus. 1 — plexus brachialis; 2 — clavicula; 3 — v. axillaris; 4 — a. axillaris; 5 — nn. pectorales medialis et lateralis; 6 — n. intercostobrachialis; 7 — n. thoracicus longus; 8 —n. thoracodorsalis; 9 — n. subscapularis; 10 — r. cutaneus lateralis et n. intercostalis; 11 — n. cutaneus brachii medialis; 12 — n. axillaris; 13 — n. radialis; 14 — n. ulnaris; 15 — n. cutaneus antebrachii medialis; 16 — n. medianus; 17 — n. musculocutaneus; 18 — fasc. lateralis; 19 — fasc. posterior; 20 — fasc. medialis.

The branches of the supraclavicular part

This part gives rise to the short branches related to the pectoral girdle:

- the *dorsal scapular nerve*, **nervus dorsalis scapulae** runs to the *levator scapulae* and the *rhomboid muscles*;
- the *long thoracic nerve*, **nervus thoracicus longus** supplies the neighboring *serratus anterior*;
- the *suprascapular nerve*, **nervus suprascapularis** crosses the suprascapular notch and reaches supraspinous and infraspinous fossae. It supplies the respective muscles and the joint capsule of the shoulder joint;
- the *subclavian nerve*, **nervus subclavius** supplies the muscle of the same name;
- the *lateral* and *medial pectoral nerves*, **nervi pectorales lateralis**

et medialis supply the pectoralis major and the pectoralis minor;

- the *subscapular nerve*, **nervus subscapularis** supplies the *subscapularis* and the *teres major*;
- the *thoracodorsal nerve*, **nervus thoracodorsalis** runs along the lateral border of scapula; it supplies the *latissimus dorsi*;
- the *axillary nerve*, **nervus axillaris** is the greatest of the short branches. It arises from the posterior cord and proceeds to the *quadrangular foramen*. Upon passing the foramen, the nerve loops around the surgical neck of humerus and reaches the posterior surface of shoulder. There it supplies the *deltoid* and the *teres minor*. Apart from this, the nerve gives some fibers to the joint capsule of the shoulder joint and to skin of the posterolateral surface of shoulder.

The infraclavicular part

The cords of the infraclavicular part give rise to the long branches that terminate within the various areas of the arm:

- the *musculocutaneous nerve*, **nervus musculocutaneus** arises from the lateral cord then traverses the *coracobrachialis* and appears in between the *biceps brachii*, **musculus biceps brachii** and the *brachialis*, **musculus brachialis**. It gives the *muscular branches*, **rami musculares** to the entire anterior group of brachial muscles (the *coracobrachialis*, the *biceps brachii* and the *brachialis*). The cutaneous branch of the nerve — the *lateral cutaneous nerve of forearm*, **nervus cutaneous antebrachii lateralis** arises from under the lateral margin of the biceps brachii and penetrates the fascia to terminate within the skin of anterolateral area of forearm (Fig. 39);

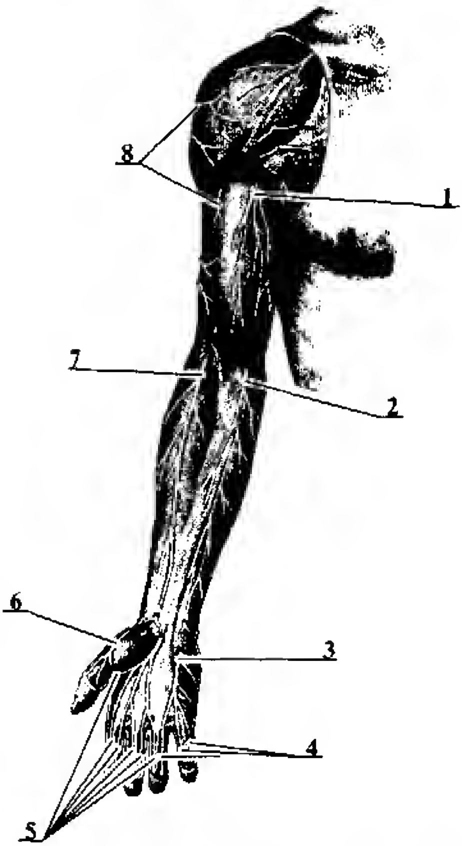


Fig. 39. The cutaneous nerves of right upper limb (anterior aspect). 1 — n. cutaneus brachii medialis; 2 — n. cutaneus antebrachii medialis; 3 — r. superficialis n. ulnaris; 4 — nn. digitales palmares proprii (n. ulnaris); 5 — nn. digitales palmares proprii (n. medianus); 6 — r. superficialis n. radialis; 7 — n. cutaneus antebrachii lateralis (n. musculocutaneus); 8 — n. cutaneus brachii lateralis superior (n. axillaris).

- the *medial cutaneous nerve of arm*, **nervus cutaneous brachii medialis** a thin nerve that arises from the medial cord and terminates within the skin of medial area of arm;
- the *medial cutaneous nerve of forearm*, **nervus cutaneous antebrachii medialis** also arises from the medial cord. The nerve runs to the forearm and terminates within the skin of its anteromedial area.

Three other nerves of the group – the median, the ulnar and the radial nerves are the principal nerves of upper limb.

The median nerve, nervus medianus

Topography of the median nerve

The median nerve arises from two roots given by the medial and the lateral cords (the medial and the lateral roots). In the arm region, the nerve joins the common neurovascular bundle that runs along the medial bicipital groove. In the forearm region, the nerve enters the cubital fossa and quits it via the space between the heads of the pronator teres. Upon escaping from the fossa, the nerve lies in between the *flexor digitorum superficialis* and the *flexor digitorum profundus*, **musculi flexores digitorum superficialis et profundus** (Fig. 40). Passing so on, the nerve lies within the *median sulcus* that leads to the *carpal tunnel*, **canalis carpi**. As the nerve appears on the palmar surface of hand, it splits into three *common palmar digital nerves*, **nervi digitales palmares communes** that in turn give seven *proper palmar digital nerves*, **nervi digitales palmares proprii**. These terminal branches run to both aspects of fingers 1 through 3 and to the radial aspect of the 4th finger (Fig. 41).

Responsibility areas of the median nerve

The median nerve gives no branches in the arm area (namely from origi-

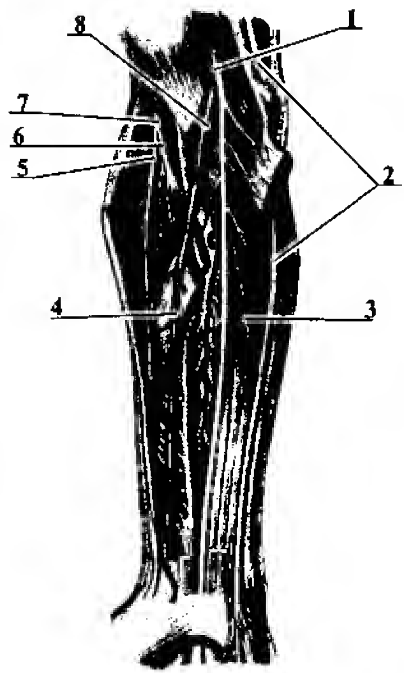


Fig. 40. The nerves of forearm, anterior aspect (the superficial muscles are removed). 1 – n. medianus; 2 – n. ulnaris; 3 – a. ulnaris; 4 – a. radialis; 5 – r. superficialis n. radialis; 6 – r. profundus n. radialis; 7 – n. radialis; 8 – a. brachialis.

nation point down to the cubital fossa). The first branches to arise are the branches to the joint capsule of the elbow joint.

In the forearm area, the nerve supplies both *pronators* (**musculi pronatores teres et quadratus**) and all flexors except for the *flexor carpi ulnaris* and the ulnar half of the *flexor digitorum profundus*, **musculus flexor digitorum profundus**. The deep muscles of forearm are under responsibility of the *anterior interosseous nerve*, **nervus interosseus anterior** that runs along the anterior interosseous membrane. This nerve terminates at the joint capsule of the joint of wrist.

In the palmar area, the motor branches supply two lateral *lumbricals* and all muscles of thumb except for the *abductor pollicis* and the deep head of the *flexor pollicis brevis*. The cutaneous branches supply the skin of the thenar, of the median portion of the palmar surface of hand and of the palmar surface of fingers 1 through 3 including the radial aspect of the 4th finger (Fig. 42).

Apart from this, the nerve gives small twigs to the dorsal surface of the 2nd and the 3rd fingers together with the radial aspect of the 4th finger.

Clinical applications

Injury to the median nerve results in inability to pronate the forearm and to oppose the thumb. Flexion of the fingers and the wrist gets affected partially because of the ulnar nerve assistance. Atrophy of the thenar muscles caused by such injury gives a characteristic look to the hand (the ape's wrist). Motor disorders are usually accompanied by the sensory disorders within the respective areas of responsibility.

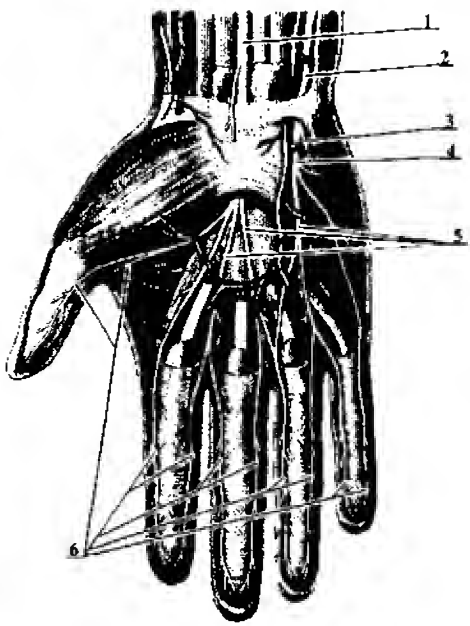


Fig. 41. The nerves of hand, palmar surface. 1 — n. medianus; 2 — n. ulnaris; 3 — r. profundus n. ulnaris; 4 — r. superficialis n. ulnaris; 5 — nn. digitales palmares communes; 6 — nn. digitales palmares proprii.

The ulnar nerve, nervus ulnaris

Topography of the ulnar nerve

The ulnar nerve arises from the medial cord of the brachial plexus.

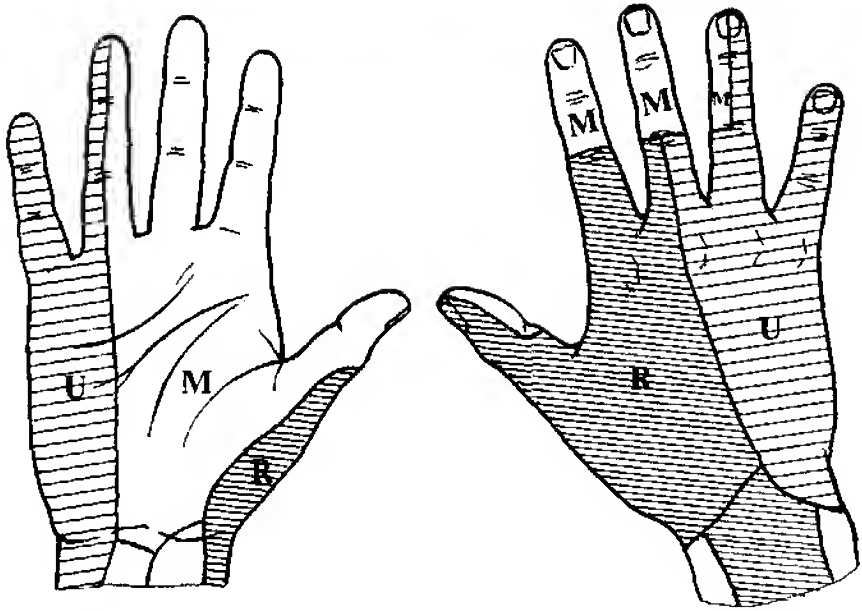


Fig. 42. Responsibility areas of the ulnar (U), the median (M) and the radial (R) nerves.

In the beginning of its route, the nerve runs along the medial bicipital groove within the common neurovascular bundle. In the inferior half of the arm, the nerve detaches from the bundle and proceeds to the ulnar groove situated on the posterior surface of the *medial epicondyle*, **epicondylus medialis** of the humerus. There the nerve runs covered by fascia and skin only. Within the forearm region, the nerve runs along the *ulnar groove* of forearm together with the ulnar artery. On reaching the lower third of the forearm, the nerve splits into the *dorsal branch*, **ramus dorsalis** and the *palmar branch*, **ramus palmaris**.

The branches and responsibility areas of the ulnar nerve

Like the median nerve, the ulnar nerve supplies but nothing in the arm area. The first branches given are the branches to the joint capsule of the elbow joint. Within the forearm and the hand, the nerve gives branches as follows:

- the *muscular branches*, **rami musculares** to the *flexor carpi ulnaris* and the ulnar half of the *flexor digitorum profundus*;
- the *dorsal branch*, **ramus dorsalis** that arises from the principal trunk within the inferior third of the forearm. The branch runs below the tendon of the flexor carpi

ulnaris to reach the dorsal surface of the hand where it splits into the dorsal digital nerves (they arise as three branches that further split into five terminal branches) (Fig. 43);

- the *dorsal digital nerves*, **nervi digitales dorsales** supply the skin of the medial aspect of the hand and the skin of the dorsal surface of the 4th and the 5th fingers including the ulnar half of the 3rd finger;
- the *palmar branch*, **ramus palmaris** arises at the same level as the dorsal yet it runs on along the ulnar groove with the neighboring ulnar blood vessels. On reaching the pisiform bone, the nerve gives off the superficial and the deep branches;
- the *superficial branch*, **ramus superficialis** supplies the skin of hypothenar and the medial aspect of hand together with underlying *palmaris brevis*. The branch gives off three *proper palmar digital nerves*, **nervi digitales palmares proprii** to the skin of the palmar surface of the 5th finger and of the ulnar aspect of the 4th finger;
- the *deep branch*, **ramus profundus** reaches the deeper palmar layers where it runs along the deep palmar arch. It supplies all hypothenar muscles, all interossei muscles, the third and the fourth lumbricals and two thenar muscles – the *adductor pollicis* and the deep head of the *flexor pollicis brevis*.

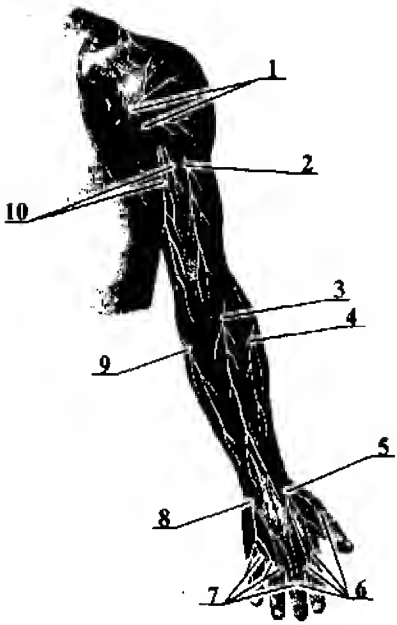


Fig. 43. The cutaneous nerves of right upper limb (posterior aspect). 1 – n. cutaneus brachii lateralis superior (n. axillaris); 2 – n. cutaneus brachii posterior (n. radialis); 3 – n. cutaneus antebrachii posterior (n. radialis); 4 – n. cutaneus antebrachii lateralis (n. musculocutaneus); 5 – r. superficialis n. radialis; 6 – nn. digitales dorsales (n. radialis); 7 – nn. digitales dorsales (n. ulnaris); 8 – r. dorsalis n. ulnaris; 9 – n. cutaneus antebrachii medialis; 10 – n. cutaneus brachii medialis.

Clinical applications

Injury to the ulnar nerve results in impaired flexion in the joint of wrist and in inability to abduct the fingers (including the thumb). Because of prevailing extensors and paralyzed interossei, the hand acquires a look of the bird's foot. Sensory disorders within the respective areas are also observed.

The radial nerve, nervus radialis

Topography and branches of the radial nerve

The radial nerve is rather a large nerve that arises from the posterior cord of brachial plexus. In the arm region, the nerve passes within the *radial canal*, **canalis nervi radialis seu canalis humeromuscularis** along with the deep artery of arm. Both artery and nerve run spirally down along the *radial groove*. Here the nerve is covered with the *triceps brachii*.

The nerve quits the canal via its inferior opening (in between the *brachialis* and the *brachioradialis*) that leads to the cubital fossa. Here, at the head of radius, the nerve splits into the superficial and the deep branches:

- the *deep branch*, **ramus profundus** runs below the *supinator* to the posterior surface of forearm where it gives off numerous muscular branches. The longest nerve of this group is the *posterior interosseous nerve*, **nervus interosseus antebrachii posterior** that runs along the interosseous membrane to reach the joint of wrist;
- the *superficial branch*, **ramus superficialis** runs within the radial groove along with the radial artery. In the lower portion of the forearm, the branch passes in between the radius and the *brachioradialis* to reach the dorsal surface of the hand. There, the branch gives off the *dorsal digital branches*, **nervi digitales dorsales**.

Responsibility areas of the radial nerve

The radial nerve is responsible for the posterior surface of the upper limb.

In the arm region, it supplies the *triceps brachii* and the *anconeus*. Here it also gives rise to the *posterior cutaneous nerve of arm*, **nervus cutaneus brachii posterior** that supplies the skin of the arm and to the *posterior cutaneous nerve of forearm*, **nervus cutaneus antebrachii posterior**.

The forearm, the deep branch supplies all extensors, the *supinator* and the *brachioradialis*.

Within the hand, the nerve supplies the skin only. Its superficial branch is responsible for the dorsal surface of hand where it supplies skin of its lateral aspect and skin of the dorsal surface of the 1st and the 2nd fingers and the radial aspect of the 3rd finger. In the 2nd and the 3rd fingers, the nerve supplies the areas related to the proximal phalanges; the rest is under responsibility of the median nerve.

Clinical applications

Fractures of humerus may result in damage of the canal-related part of radial nerve.

High-point injury to the radial nerve results in paralysis of the extensors with typical wrist slack because of inability of the extensors to counteract the flexors. Skin sensitivity within the respective area gets impaired as well.

THE ANTERIOR RAMI OF THORACIC NERVES

The anterior branches of the thoracic nerves retain segmental arrangement as opposed to the anterior cervical branches that form plexuses. These branches are related to the intercostal spaces and thus are referred to as the intercostal nerves.

The greater portion of the first thoracic nerve joins the brachial plexus and the smaller portion constitutes rather a thin first intercostal nerve.

The anterior ramus of the twelfth thoracic nerve is the *subcostal nerve*, **nervus subcostalis** found below the twelfth rib; the nerve gives some fibers to the lumbar plexus.

The *intercostal nerves*, **nervi intercostales**

Topography of the intercostal nerves

The intercostal nerves occupy the costal grooves of the bodies of ribs. From the origination point and up to the costal angle each nerve is covered with parietal pleura; the portion related to the body of rib passes in between the external and the internal intercostal muscles. The nerves 1 through 6 reach the sternum; the rest quit the intercostal spaces and reach the anterior abdominal wall. There they run in between the internal oblique and the transversus abdominis to enter the rectus sheath and meet the nerves from the opposite side at the anterior median line (Fig. 44).

Responsibility areas of the thoracic nerves

The intercostal nerves are the mixed nerves i.e. they comprise the sensory and the motor branches:

- the motor branches supply the muscles of chest proper (both *external* and *internal intercostal muscles*, **musculi intercostales externi et interni**, the *transversus thoracis* (Lat. Id.) and the *subcostales*) and the abdominal muscles (both *external* and *internal oblique*, **musculi obliquus externus et internus**, the *transversus abdominis*, **musculus transversus abdominis**, the *rectus abdominis*, **musculus rectus abdominis**, the *pyramidalis*, **musculus pyramidalis** and the *quadratus lumborum*, **musculus quadratus lumborum**);
- the sensory branches supply the skin of the thorax and the abdomen. Each intercostal nerve gives rise to the *anterior* and the *lateral cutaneous branches (pectoral and abdominal)*, **rami cutanei anterior et posterior (pectoralis et abdominales)**. The anterior branches supply the medial portion of the respective region and the lateral branches – the lateral portions of the same regions. The anterior branches arise along the margins of sternum and the rectus abdominis and the lateral branches arise along the midaxillary line.

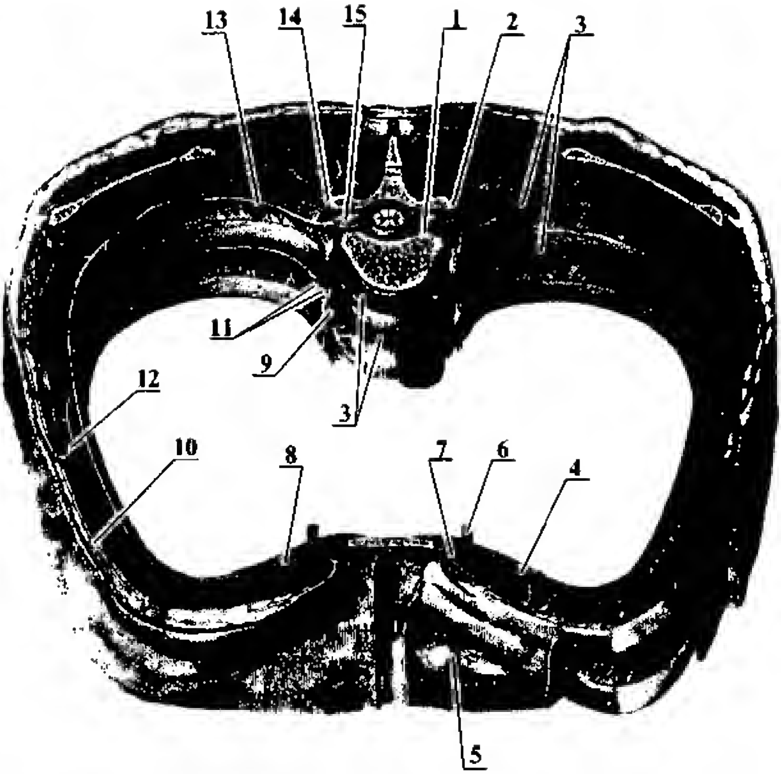


Fig. 44. The intercostal nerves and arteries. 1 — r. spinalis a. intercostalis posterioris; 2 — r. dorsalis a. intercostalis posterioris; 3 — aa. intercostales posteriores; 4 — a. intercostalis anterior; 5 — a. epigastrica superior; 6 — a. thoracica interna; 7 — r. perforans a. thoracicae internae; 8 — r. cutaneus anterior n. intercostalis; 9 — truncus sympathicus; 10 — r. mammarius lateralis; 11 — rr. communicantes; 12 — r. cutaneus lateralis n. intercostalis; 13 — n. intercostalis (r. anterior n. spinalis thoracicus); 14 — r. posreior n. spinalis thoracicus; 15 — ganglion spinale.

THE LUMBAR PLEXUS, PLEXUS LUMBALIS (Th12 — L4)

Topography of the lumbar plexus

The lumbar plexus arises from the anterior branches of three upper lumbar nerves and partially from the twelfth thoracic nerve and fourth lumbar nerve. It resides within the lumbar region in between the transverse processes of related lumbar vertebrae posterior and in depth of the *psoas major* (Fig. 45). Inferiorly, the lumbar plexus communicates with the sacral plexus. Most of the rami arise from behind the lateral border of the

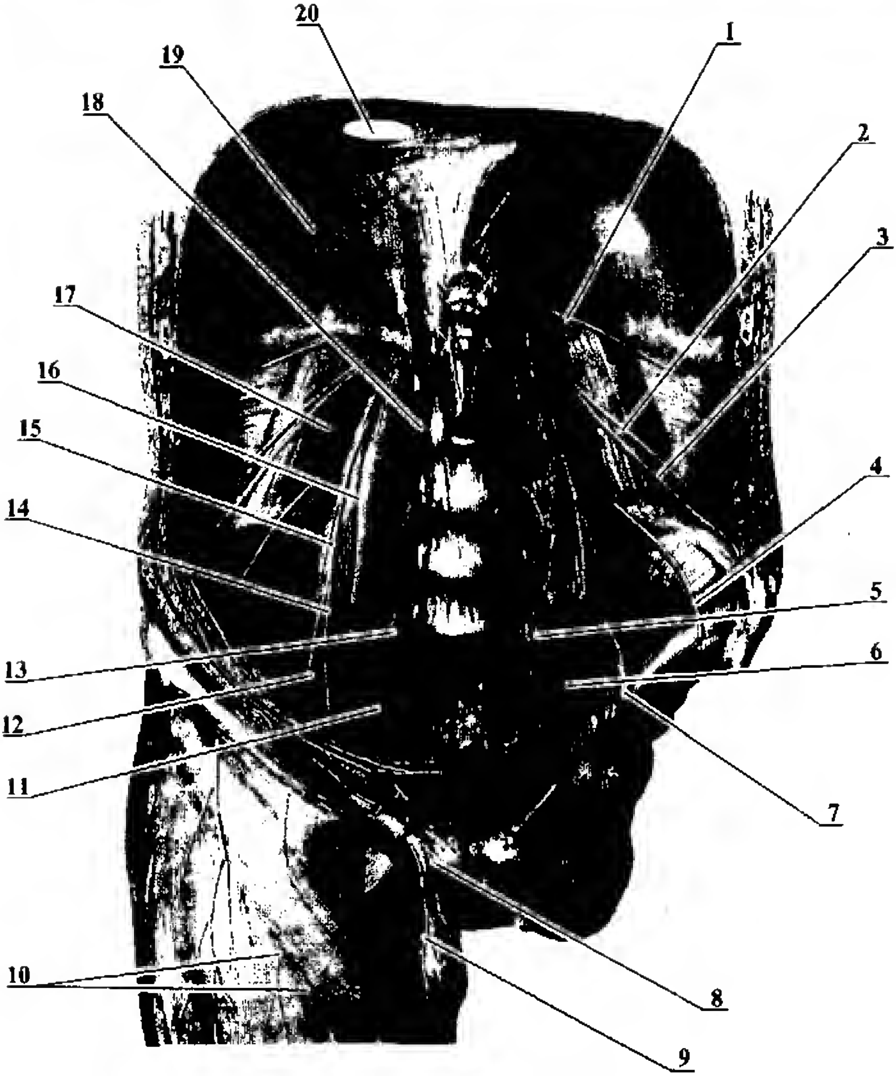


Fig. 45. The lumbar and the sacral plexuses (anterior view). 1 – n. subcostalis; 2 – n. iliohypogastricus; 3 – n. ilioinguinalis; 4 – n. cutaneus femoris lateralis; 5 – n. obturatorius; 6 – n. obturatorius accessorius; 7 – n. femoralis; 8 – nn. scrotales (labiales) anteriores; 9, 14 – r. genitalis n. genitofemoralis; 10 – rr. cutanei anteriores n. femoralis; 11 – plexus sacralis; 12 – r. femoralis n. genitofemoralis; 13 – truncus lumbosacralis; 15 – n. genitofemoralis; 16 – m. psoas major; 17 – m. quadratus lumborum; 18 – truncus sympathicus; 19 – m. phrenicus; 20 – foramen venae cavae.

psoas major; one ramus traverses the muscle (the *genitofemoral nerve*) and one branch arises from behind the medial border of the muscle (the *obturator nerve*).

The branches of the lumbar plexus

The greatest branches of the lumbar plexus are the femoral nerve and the obturator nerve. The plexus also gives rise to several smaller branches that terminate within the skin and the muscles of the abdomen, the lower limb and the external genitals:

- the *muscular branches*, **rami musculares** supply both psoas muscles, the quadratus lumborum and the lumbar intertransversarii;
- the *iliohypogastric nerve*, **nervus iliohypogastricus** arises from behind of the lateral border of the psoas major and runs in between the transversus abdominis and the external oblique. The nerve supplies all abdominal muscles, the skin of hypogastrium and the skin of the gluteal region (its superolateral portion);
- the *ilio-inguinal nerve*, **nervus ilioinguinalis** in the beginning of its way runs parallel and below the previous nerve but enters the inguinal canal. Within the canal, the nerve resides anterior to the spermatic cord (the round ligament of uterus); it terminates within the skin of the pubic region and the scrotum (the labia majora) and gives some branches to both oblique muscles and the transversus abdominis;
- the *genitofemoral nerve*, **nervus genitofemoralis** traverses the psoas major and descend along its anterior surface; there it gives the *genital branch*, **ramus genitalis** and the *femoral branch*, **ramus femoralis**. The genital branch enters the inguinal canal where runs posterior to the spermatic cord (the round ligament of uterus). It supplies the *cremaster*, the *dartos muscle*, the skin of scrotum (the labia majora) and the skin of superomedial surface of thigh. The femoral branch passes through the vascular space below the inguinal ligament to a small upper portion of the femoral triangle;
- the *lateral cutaneous nerve of thigh*, **nervus cutaneus femoris lateralis** arises from behind of the lateral border of the psoas major and runs slantwise down to the *anterior superior iliac spine*. On bypassing the spin, the nerve proceeds to the lateral surface of thigh.

The *obturator nerve*, **nervus obturatorius** is quite a large branch of the lumbar plexus. It arises from behind of the medial border of the psoas major and runs along the lesser pelvis wall to enter the obturator canal that leads the nerve to the thigh. Within the thigh, the nerve resides in between the adductors and splits into the anterior and the posterior branches. The nerve supplies the neighboring adductors, the *pectineus*, the *gracilis*, the *obturator externus* and the joint capsule of the hip joint.

Apart from the obturator nerve, the *accessory obturator nerve*, **nervus**

obturatorius accesorius is also distinguishable.

The *femoral nerve*, **nervus femoralis** is the greatest branch of the lumbar plexus.

Topography of the femoral nerve

The nerve arises from behind the lateral border of the psoas major and proceeds to the thigh region via the muscular space. Within the thigh region, the nerve resides in the femoral triangle laterally from the femoral artery (Fig. 46).

The branches of the femoral nerve

In the femoral triangle, the femoral nerve fans out to give numerous branches:

- the *muscular branches*, **rami musculares** supply the quadriceps femoris and the pectineus;

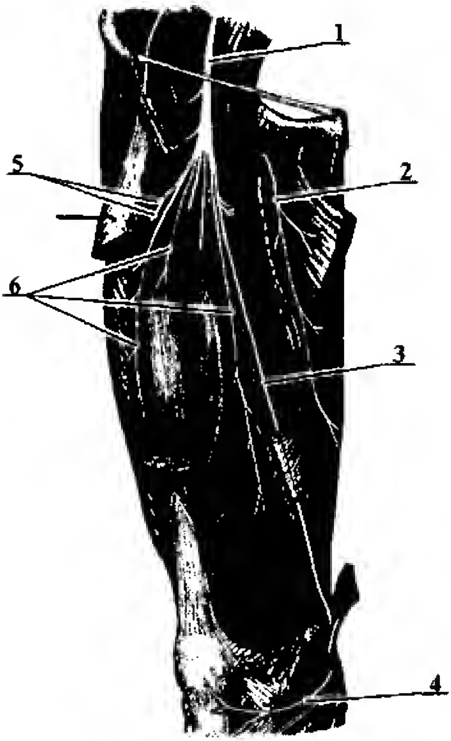


Fig. 46. The nerves of thigh, anterior view (the superficial muscles are removed). 1 — n. femoralis; 2 — n. obturatorius; 3 — n. saphenus; 4 — r. infrapatellaris; 5 — rr. musculares n. femoralis; 6 — rr. cutanei anteriores n. femoralis.

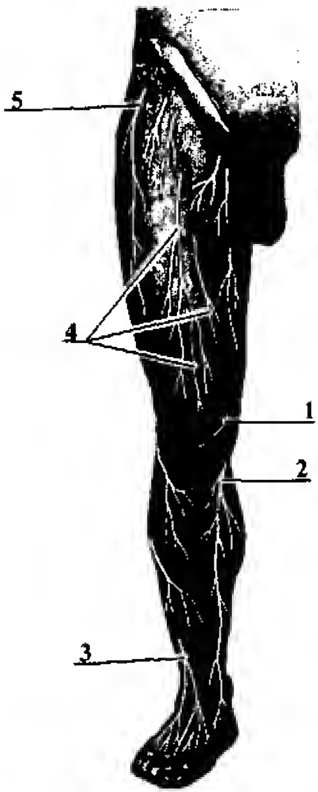


Fig. 47. The cutaneous nerves of right lower limb (anterior aspect). 1 — r. infrapatellaris; 2 — n. saphenus; 3 — n. fibularis superficialis; 4 — rr. cutanei anteriores n. femoralis; 5 — n. cutaneus femoris lateralis.

- the *anterior cutaneous branches*, **rami cutanei anteriores** penetrate the fascia and terminate in the skin of anteromedial area of thigh;
- the *saphenous nerve*, **nervus saphenus** is the longest branch of the femoral nerve. It enters the adductor canal together with the femoral artery and the femoral vein. Upon escaping from the canal via its anterior opening (the adductor hiatus) the nerve runs along the medial aspect of shin and foot together with the *great saphenous vein* and reaches the great toe. In the thigh are, the nerve gives no branches; the first branch to arise is the *infrapatellar branch*, **ramus infrapatellaris**. It supplies the skin of the medial surface of knee joint and ofthe patellar area. Apart from this, the nerve supplies the skin of the medial aspect of shin and foot up to the great toe.

Clinical applications

Injury to the femoral nerve leads to paralysis of the quadriceps femoris and thus to inability to extend the knee joint. When walking, the victim is unable to withhold extension of leg and the foot strikes against the ground with its entire surface. Injury to the obturator nerve affects abduction of thigh and crossing of legs.

THE SACRAL PLEXUS, PLEXUS SACRALIS (L4 — L5\S1 — S4)

Topography of the sacral plexus

The sacral plexus is the greatest of all nervous plexuses in the human body. It arises from merged upper four sacral nerves, the fifth lumbar nerve and a part of the fourth lumbar nerve. the fourth and the fifth lumbar nerves merge into a single *lumbosacral trunk*, **truncus lumbosacralis** that descends to the lesser pelvis cavity and joins the sacral nerves. The lowest portion of the sacral plexus formed of the fifth sacral nerves (S5) and the coccygeal nerve (Co1) is the *coccygeal plexus*, **plexus coccygeus**.

The sacral plexus appears as a thick triangular plate adherent to the pelvic wall (namely to the *piriformis*). The branches given quit the lesser pelvis via the suprapiriform and the infrapiriform foramina as the short and the long branches. The greatest nerve of the plexus is the sciatic nerve.

The short branches

These branches stay within the pelvic girdle region to supply the pertaining muscles and skin:

- the *muscular branches*, **rami musculares** supply the piriformis, the obturator internus, both gemelli and the quadratus femoris;
- the *superior gluteal nerve*, **nervus gluteus superior** runs via the su-

prapiriform foramen to the gluteus medius, the gluteus minimus and the tensor fasciae latae;

- the *inferior gluteal nerve,* **nervus gluteus inferior** runs via the infrapiriform foramen to the gluteus maximus and the joint capsule of the hip joint;
- the *pudendal nerve,* **nervus pudendus** quits the lesser pelvis via the infrapiriform foramen, loops around the ischial spine and enters the ischio-anal fossa via the lesser sciatic foramen. The nerve supplies the external anal sphincter and other perineal muscles together with related skin. The terminal branch of the nerve called the *dorsal nerve of penis (clitoris),* **nervus dorsalis penis (clitoridis)** runs to the dorsal surface of the penis (clitoris). The nerve supplies the corpora cavernosa of the penis (clitoris), the external urethral sphincter, skin of penis (in males) or skin of both labia majora and minora (in females).

The long branches

The long branches are the posterior cutaneous nerve of thigh and the sciatic nerve.

The *posterior cutaneous nerve of thigh,* **nervus cutaneus femoris posterior** runs via the infrapiriform foramen to skin of the posterior surface of thigh (Fig. 48, 49). The nerve also gives the *inferior cluneal nerves,* **nervi clunium inferiors** to skin of gluteal region.

The *sciatic nerve,* nervus ischiadicus

Topography of the sciatic nerve

The sciatic nerve is the greatest nerve of the human body. It comprises nearly all branches that participate in formation of the sacral plexus. The nerve quits the lesser pelvis cavity via the infrapiriform foramen and runs on below the gluteus maximus. Somewhat below the escape point, the nerve enters in between the ischial tuberosity and the greater trochanter, proceeds onto the quadratus lumborum surface and finally becomes evident within the thigh region, arising from under the lower border of the gluteus maximus (Fig. 49). Within the thigh region, the nerve runs deep in between the neighboring muscles. On reaching the upper angle of the popliteal fossa, the nerve splits into the terminal branches – the tibial nerve and the common fibular nerve. High point branching of the sciatic nerve is of common occurrence. In this case, the terminal branches of the nerve arise within the thigh and run together to responsibility areas. The principal trunk of the nerve gives off the muscular branches to the posterior group of muscles of thigh (to the semitendinosus, the semimembranosus and the long head of biceps femoris).

Clinical applications

Chilling of the area related to the nerve results in neuritis of the sciatic nerve (sciatica). The state features painful sensation within the ischial area and the posterior portion of the

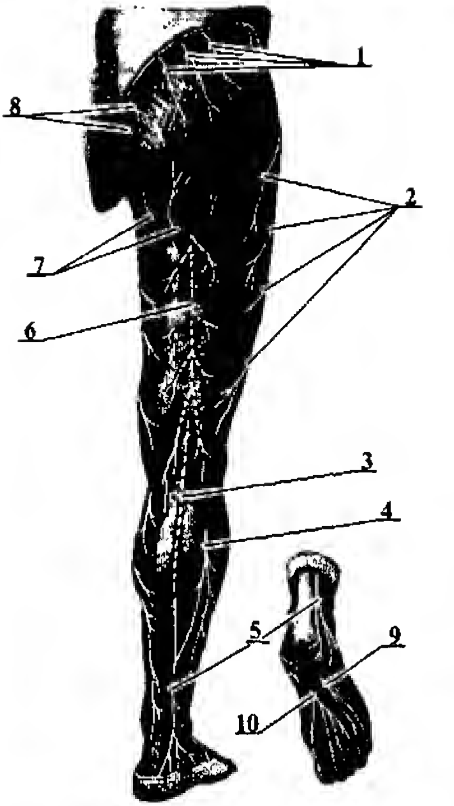


Fig. 48. The cutaneous nerves of right lower limb (posterior aspect). 1 — nn. clunium superiores; 2 — n. cutaneus femoris lateralis; 3 — n. cutaneus surae medialis; 4 — n. cutaneus surae lateralis; 5 — n. suralis; 6 — n. cutaneus femoris posterior; 7 — nn. clunium inferiores; 8 — nn. clunium medii; 9 — n. plantaris lateralis; 10 — n. plantaris medialis.

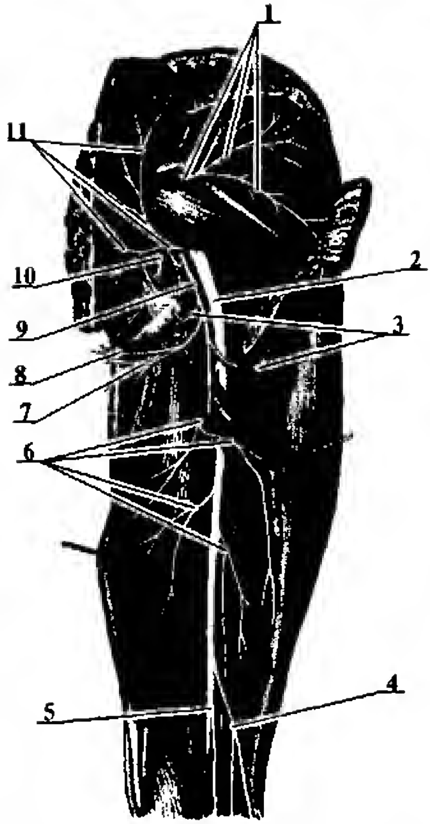


Fig. 49. The nerves of thigh, posterior view. 1 — n. gluteus superior; 2 — n. ischiadicus; 3 — nn. clunium inferiores; 4 — n. fibularis communis; 5 — n. tibialis; 6 — rr. musculares (n. ischiadicus); 7 — n. cutaneus perforans; 8 — r. perinealis; 9 — n. cutaneus femoris posterior; 10 — n. pudendus; 11 — n. gluteus inferior.

thigh. The condition may even feature sensory and motor disorders.

The *tibial nerve*, nervus tibialis

Topography of the tibial nerve

The tibial nerve arises directly from the sciatic nerve and runs vertically down to the popliteal fossa (Fig. 50). Within the fossa, the nerve occupies the most superficial position with respect to neighboring popliteal artery and popliteal vein. From the popliteal fossa, the nerve proceeds to the *cruropopliteal canal.* On escaping from the canal, the nerve loops around

the medial malleolus and gives some branches to the ankle joint. Below the flexor retinaculum, the nerve gives off its terminal branches – the medial and the lateral plantar nerves.

The branches of the tibial nerve

The tibial nerve gives the branches as follows:

- the *muscular branches*, **rami musculares** supply all posterior muscles of shin (the igastrocnemius, the *soleus*, the *plantaris*, the *popliteus* etc.);
- the *medial sural cutaneous nerve*, **nervus cutaneus surae medialis** arises from the tibial nerve yet within the popliteal fossa. It runs laterally and merges with the lateral sural cutaneous nerve (from the common fibular nerve) to form the sural nerve;
- the *sural nerve*, **nervus suralis** descends midline along the posterior surface of shin together with the *small saphenous vein*. Upon reaching the ankle joint, the sural nerve loops around the lateral malleolus, gives the *lateral calcaneal branches*, **rami calcanei laterales** and becomes continuous with the *lateral dorsal cutaneous nerve*, **nervus cutaneus dorsalis lateralis** (Fig. 48). The nerve supplies skin of the posterolateral surface of shin and the lateral aspect of foot up to the little toe;

Fig. 50. The nerves of shin (the triceps surae is removed). 1 – n. tibialis; 2 – n. fibularis communis; 3 – n. cutaneus surae medialis; 4 – n. cutaneus surae lateralis; 5 – n. suralis.

The *medial plantar nerve*, **nervus plantaris medialis** runs along the groove of the same name (Fig. 51). Within the distal portion of foot, the nerve splits into the *common plantar digital nerves*, **nervi digitales plantares communes** that in turn branch into the *proper plantar digital nerves*, **nervi digitales plantares proprii**. They supply the medial aspect of foot, the toes 1 through 3 and a medial half of the fourth toe.

The muscular branches of the nerve supply the *flexor digitorum brevis*, all muscles of great toe (except for the *adductor hallucis* and the lateral

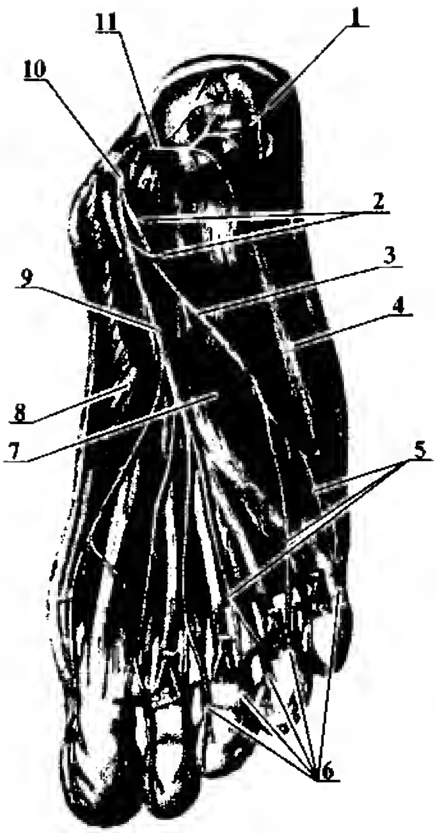


Fig. 51. The plantar nerves. 1 — r. calcaneus lateralis; 2 — rr. musculares; 3 — n. plantaris lateralis 4 — m. abductor digiti minimi; 5 — nn. digitales plantares communes; 6 — nn. digitales plantares proprii; 7 — m. quadratus plantae; 8 — m. abductor hallucis; 9 — n. plantaris medialis; 10 — n. tibialis; 11 — r. calcaneus medialis.

head of *flexor hallucis brevis*) and two lumbricals (1 and 2).

The *lateral plantar nerve*, **nervus plantaris lateralis** also occupies the groove of the same name; it splits into the *superficial branch*, **ramus superficialis** and the *deep branch*, **ramus profundus**. The superficial branch gives off the *common plantar digital nerves*, **nervi digitales plantares communes**, which become continuous with the *proper plantar digital nerves*, **nervi digitales plantares proprii**. They supply the lateral aspect of foot, the fifth toe and a lateral half of the fourth toe. The deep branch supplies all interossei, two lumbricals, the *adductor hallucis*, and the lateral head of *flexor hallucis brevis*.

Clinical applications

Injury to the tibial nerve results in paralysis of pertaining flexors. The foot thus becomes permanently extended and the toes may resemble the claws.

The *common fibular nerve*, **nervus fibularis communis**

Topography of the nerve

From the arise point, the nerve runs laterally to reach the head of fibula. At that point, the nerve enters between the heads of the fibularis longus and slits into the superficial and the deep fibular nerves. Yet within the popliteal fossa, the nerve gives the *lateral sural cutaneous nerve*, **nervus cutaneus surae lateralis** that merges with the medial sural cutaneous nerve to form the sural nerve. Very often, the nerves merge at the lower third of shin or even run separately.

The *superficial fibular nerve*, **nervus fibularis superficialis** runs within the superior musculoperoneal canal (in between the fibilaris longus and the fibula). The nerve quits the canal in the lower half of shin and runs on superficially down to the dorsal sur-

face of foot. There the nerve terminates with the *medial dorsal cutaneous nerve*, **nervus cutaneus dorsalis medialis** and the *lateral dorsal cutaneous nerve*, **nervus cutaneus dorsalis lateralis**. Both nerves supply the respective areas of the dorsal surface of foot. It also leaves some *muscular branches*, **rami musculares** to the fibulares muscles while running within the musculoperoneal canal.

The *deep fibular nerve*, **nervus fibularis profundus** passes along the interosseous membrane of shin below the anterior group of pertaining muscles. Just like the superficial nerve, it reaches the dorsal surface of foot yet it is responsible for a small area between the first and the second toes.

Within the shin, the nerve supplies the anterior group of muscles (the tibialis anterior, the extensor digitorum longus and the extensor hallucis longus) and the joint capsule of ankle joint.

Clinical applications

Injury to the fibular nerve leads to inability to extend and to pronate the foot. The foot in this case hangs down and laterally.

Practice questions

1. Name the principal components of the peripheral nervous system and give their general characteristics.
2. Describe formation, topography and branches of the spinal nerves. Explain relations of the spinal nerves to the spinal segments.
3. Describe contents, topography and responsibility areas of the posterior branches of spinal nerves.
4. Describe the posterior branch of the first cervical nerve including contents, topography and responsibility areas.
5. Describe the posterior branch of the second cervical nerve including contents, topography and responsibility areas.
6. Describe the anterior branches of spinal nerves with featured structural and topographical regularities.
7. Describe formation, branches, topography and responsibility areas of the thoracic nerves.
8. Describe formation, branches, topography and responsibility areas of the intercostal nerves.
9. Describe structural features of the nervous plexuses.
10. Describe formation, branches, topography and responsibility areas of the cervical plexus.
11. Describe formation, branches, topography and responsibility areas of the phrenic nerve.
12. Describe formation, topography, parts and classification of branches of the brachial plexus.
13. Describe the trunks and the cords of the brachial plexus.
14. Describe the supraclavicular part of the brachial plexus.
15. Describe the short branches of the brachial plexus with featured topography and responsibility areas.

16. Describe the axillary nerve.
17. Describe the infraclavicular part of the brachial plexus.
18. Describe the long branches of the brachial plexus with featured topography and responsibility areas.
19. Describe the musculocutaneous nerve.
20. Describe the median nerve.
21. Describe the ulnar nerve.
22. Describe the radial nerve.
23. Describe the long cutaneous branches of the brachial plexus.
24. Describe the lumbar plexus.
25. Describe the femoral nerve.
26. Describe the obturator nerve.
27. Describe the sacral and the coccygeal plexuses.
28. Describe the short branches of the sacral plexus.
29. Describe the pudendal nerve.
30. Describe the long branches of the sacral plexus.
31. Describe the sciatic nerve.
32. Describe the tibial nerve.
33. Describe the common fibular nerve.
34. Describe the coccygeal plexus.

AUTONOMIC DIVISION, AUTONOMIC PART OF PERIPHERAL NERVOUS SYSTEM; DIVISIO AUTONOMICA, PARS AUTONOMICA SYSTEMATIS NERVOSI PERIPHERICI

The autonomic division of peripheral nervous system regulates physiological processes of the human organism like blood circulation, respiration, digestion, excretion and general metabolism; also, it regulates tissue trophic processes. The autonomic division acts relatively independently from the cerebral cortex and the organs supplied act involuntarily as well.

It is quite clear that that distinguishing of the somatic and the autonomic compartments is conditional and exact delimitation is not possible. Such impossibility appears due to common regulatory centers for both divisions and tight morphological and functional associations featured by them.

The somatic neurons and the interneurons of PNS like those of CNS feature topographical and synaptic associations so a reflex arc may comprise both somatic (e.g. afferent) and autonomic neurons.

Summarizing the aforesaid, the term 'autonomic nervous system' will be applied to a specific compartment of PNS but not for a separate nervous system.

A short account on autonomic nervous system studies

The nerves related to the sympathetic trunk and the vagus nerve were described yet in ancient times (by Hippocrates and Claudius Galen) though notions on these nerves were quite primitive.

In 1732, Paris anatomist J. Winslow (1669-1760) implemented a concept on the nerves that supply the viscera. In attempt to emphasize their regulatory effect on the viscera, he called those nerves sympathetic (from Greek **'sympathicos'** – compassionate or concerned).

Final deployment of the concept of sympathetic nervous system came after prominent studies by French anatomist F. X. Bichat. In 1800, Bichat distinguished the animal nervous system related to the organs of animal life and the vegetative nervous system related to the viscera (the organs of vegetative life).

Modern concepts on the autonomic division come from studies of prominent English physiologist and histologist J. Lengley (1852-1925). In 1905, he distinguished sympathetic and parasympathetic compartments and proved their opposite effects on an organism. Lengley was the first to discover preganglionic and postganglionic fibers and to find that the autonomic conduits synapse within the related ganglia. In order to emphasize

on independent activities of the vegetative nervous system he implemented the term 'autonomic nervous system'.

Works of home neuromorphologists (A.S. Dogel, B.I. Lavrentyev, M.G. Kolosov) made a great contribution into studies of autonomic nervous system. Kharkiv anatomist V.P. Vorobyov designed the methods of macro-microscopic studies of the nerves and performed detailed investigations of many autonomic plexuses. Belorussian anatomist D.M. Golub won a State Award in 1973 for studies in embryology of autonomic nervous system and re-innervation of viscera.

The autonomic division of the nervous system supplies the viscera, the non-striated muscles, the glands, the heart and the blood vessels. Running along the blood vessels, the autonomic nerves expand into the muscles to provide trophic nerve supply.

From the evolutional point of view, the autonomic nervous system is much older than the somatic division and thus it retains some primitive traits. They are the **morphological features of the autonomic nervous system**

- the featured neurons reside predominately within the autonomic ganglia outside the CNS;
- two-neuron efferent pathway from the CNS to the effectors;
- thin non-myelinated postganglionic fibers (1-4 μm) with low transmission rate;
- network-type arrangement of the postganglionic fibers that form the autonomic plexuses.

According to **functional and morphological features,** the autonomic nervous system is subdivided into the sympathetic and parasympathetic parts, which in most cases have opposite effects on an organism. Generally, the parasympathetic nervous system guards an organism by maintaining homeostasis, while the sympathetic system regulates adaptation by enhancing the trophic processes.

The viscera have double nerve supply that act in accord to optimize functioning of the systems. The blood vessels except for the coronary ones, the skin glands and the skeletal muscles are supplied by the sympathetic part only.

The autonomic nervous system comprises the regulatory centers situated within the CNS and the peripheral part represented by the autonomic nerves, the autonomic plexuses and the autonomic ganglia.

The regulatory centers of the autonomic nervous system

The **sympathetic centers** occupy the lateral grey columns of the spinal cord (the *intermediolateral nucleus*) with respect to the segments C8 through L2.

The **parasympathetic centers** reside within the brainstem (the *cranial part*) and within the sacral compartment of the spinal cord (the *sacral part*).

1. The **cranial part of the parasympathetic nervous system** features the nuclei of cranial nerves as follows:

a) the *accessory nucleus of oculomotor nerve,* **nucleus accessorius**

nervi oculomotorii situated within the midbrain;

b) the *superior salivatory nucleus,* **nucleus salivatorius superior** situated within the pons;

c) the *inferior salivatory nucleus,* **nucleus salivatorius inferior** and the *dorsal nucleus of vagus nerve,* **nucleus dorsalis nervi vagi** situated within the medulla oblongata.

2. The **sacral part** is represented with the *sacral parasympathetic nuclei,* **nuclei parasympathici sacrales** situated in between the anterior and the posterior grey columns with respect to segments S2 through S4.

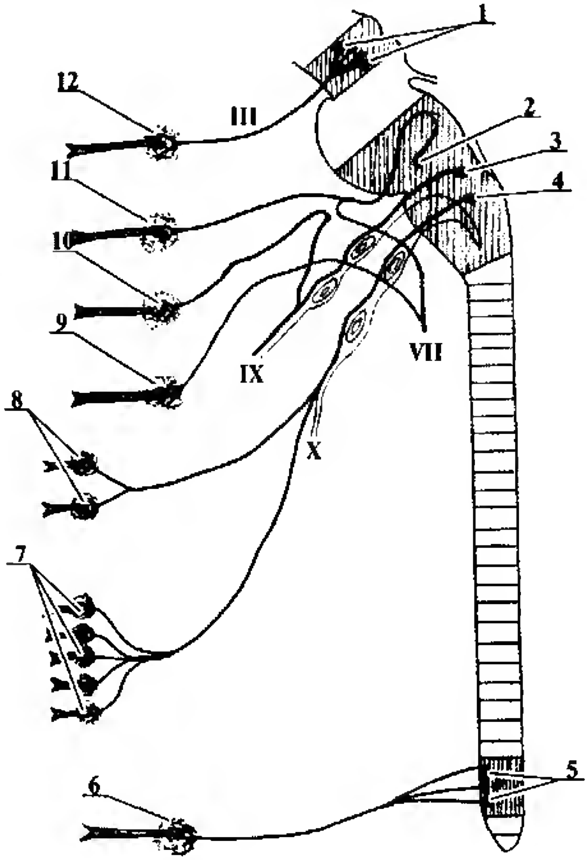


Fig. 52. Origination and responsibility areas of parasympathetic fibers. 1 — nucl. accessorius n. oculomotorii (III); 2 — nucl. salivatorius superior (VII); 3 — nucl. salivatorius inferior (IX); 4 — nucl. dorsalis n. vagi (X); 5 — nucll. parasympathici sacrales; 6 — plexus hypogastricus superior et inferior; 7 — plexus intramuralis в органах черевної порожнини; 8 — plexus intramuralis в органах грудної порожнини; 9 — ganglion submandibulare; 10 — ganglion oticum; 11 — ganglion sphenopalatinum; 12 — ganglion ciliare.

The **superior autonomic centers** dominate over the autonomic regulatory centers. They regulate activities of both sympathetic and parasympathetic parts and thus are the *suprasegmental centers*. They reside within the following compartments of the brain:

1) the medulla oblongata contains the vasculomotor, the respiratory, the vomiting and the deglutition centers;

2) the cerebellum is responsible for skin trophics, wound healing and the arrector muscles of hair;

3) the subthalamus regulates all autonomic functions, metabolism, hunger, thirst, body temperature, sexuality and activities of the endocrine glands. Activities of the subthalamus in turn is under control of the cerebral cortex (mainly from the limbic system);

4) the telencephalon regulates blood pressure, salivation and lacrimation;

5) the cerebral cortex may influence any autonomic function via the cortico-visceral associations.

The autonomic ganglia

The autonomic ganglia are the relay centers for the efferent fibers. With respect to the relay centers, the efferent fibers are subdivided into the preganglionic and postganglionic types:

- the *preganglionic nerve fibers*, **neurofibrae preganglionicae** are the axons of autonomic regulatory centers situated within the brainstem and the spinal cord. Most of them are myelinated with high transmission rate featured. They synapse within the autonomic ganglia;
- the *postganglionic nerve fibers*, **neurofibrae postganglionicae** are the axons of the autonomic ganglia. They are non-myelinated fibers (and thus are of grey color) with low transmission rate.

The autonomic ganglia are the peripheral autonomic centers. They are responsible for impulses multiplication (one ganglionic fiber is in contact with 50 or even more ganglionic neurons) and transmission rate reduction.

Classification of the autonomic ganglia

Depending on location, the ganglia are subdivided into the groups like the following:

- the *paravertebral ganglia*, **ganglia paravertebralia** that run along the lateral surfaces of the vertebral column (they are the ganglia of the sympathetic trunk);
- the *prevertebral ganglia*, **ganglia prevertebralia** that run along the anterior surface of the vertebral column (they are the ganglia of the thoracic and the abdominal autonomic plexuses). They also belong to the sympathetic nervous system;
- the *terminal ganglia*, **ganglia terminalia** that either neighbor the organ supplied (the external ganglia like the ciliary ganglion, the pterygopalatine ganglion, the submandibular ganglion or the otic ganglion) or reside deeper within the organ (the intramural ganglia).

They are the parasympathetic ganglia.

The autonomic reflex arc

The simplest autonomic reflex arc comprises three types of neurons:

The sensory (afferent) neurons of the autonomic division reside within the spinal or the cranial sensory ganglia (these ganglia are shared by somatic and autonomic divisions). The sensory ganglia consist of the pseudounipolar cells with the central and the peripheral processes featured.

The peripheral processes reach the viscera (the heart, the lungs, the stomach etc.) and terminate at the interoceptors that accept the stimuli. The central processes run to the autonomic centers (of the spinal cord and the brainstem) via the posterior roots of spinal cord and the cranial nerves.

The second neurons reside within the autonomic nuclei of the spinal cord and the brainstem; the axons of the pertaining cells are the preganglionic efferent fibers that quit the CNS within the anterior roots of spinal cord and the cranial nerves and reach the autonomic ganglia.

The third neurons form the autonomic ganglia; their axons are the postganglionic efferent fibers that reach the respective organs via the autonomic plexuses.

Thus, the efferent autonomic pathway unlike that of the somatic division comprises two neurons. The sympathetic fibers synapse within the prevertebral or the paravertebral ganglia and the parasympathetic fibers synapse within the terminal ganglia (either external or intramural).

THE SYMPATHETIC PART, PARS SYMPATHICA

The sympathetic part features two compartments — the central and the peripheral.

The sympathetic centers are the *intermediolateral nuclei* situated within the lateral grey columns of spinal cord with respect to the segments C8 through L2 (Fig. 53).

The peripheral compartment comprises the following portions:

- the paravertebral sympathetic ganglia that form the sympathetic trunks;
- the prevertebral sympathetic ganglia situated anterior to the vertebral column. They belong to numerous abdominal autonomic plexuses;
- the preganglionic sympathetic fibers that run from the sympathetic centers to the autonomic ganglia (they are the white rami communicantes and the interganglionic branches);
- the postganglionic sympathetic fibers that arise from the sympathetic ganglia and join the plexuses to reach the responsibility areas (the grey rami communicantes, the visceral branches and the sympathetic nerves);

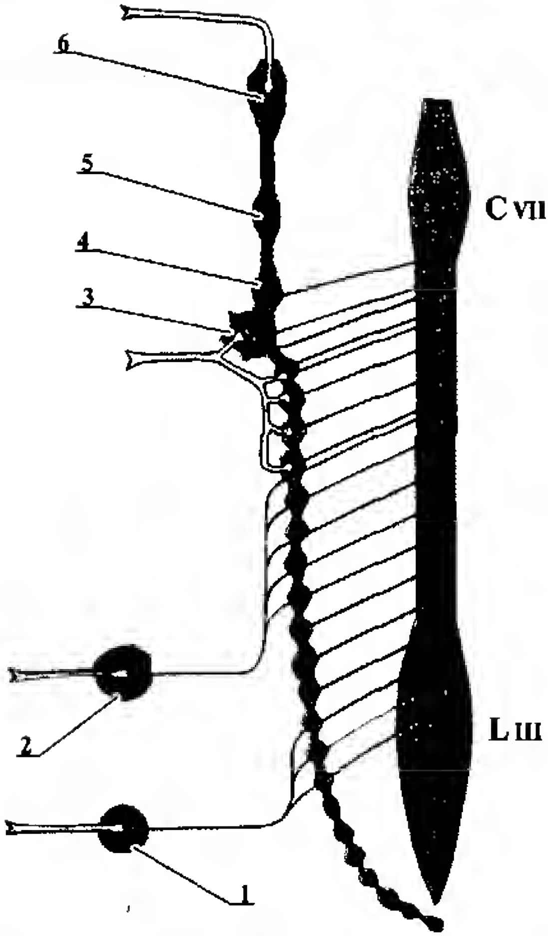


Fig. 53. Origination and responsibility areas of sympathetic fibers. 1 — ganglion mesentericus interior; 2 — ganglion coeliacus; 3 — ganglion stellatum; 4 — ganglion cervicale inferioris; 5 — ganglion cervicale medium; 6 — ganglion cervicale superius

- numerous thoracic and abdominal plexuses (the periarterial and the visceral plexuses).

The *sympathetic trunk*, **truncus sympathicus**

The paired sympathetic trunk runs from the external cranial base down to the coccyx. It comprises 20-25 *ganglia of sympathetic trunk*, **ganglia trunci sympathici** associated by the *interganglionic branches*, **rami interganglionares**. Upon reaching the coccyx, the trunks merge into a single *ganglion impar* (Lat. Id.).

The sympathetic trunk comprises the cervical, the thoracic, the lumbar and the sacral parts. The ganglia of the sympathetic trunk contain the peripheral efferent neurons of the sympathetic part. Morphologically they are referred to as the small multipolar neurons. All thoracic and two upper lumbar ganglia accept the preganglionic sympathetic fibers as the *white rami communicantes*, **rami communicantes albi** that arise from the eighth cervical, all thoracic and two upper lumbar segments. They are the axons of the *intermediolateral nucleus* of the spinal cord. The cervical, the lower lumbar, the sacral and the coccygeal ganglia lack rami communicantes. The preganglionic fibers reach these ganglia directly via the *interganglionic branches*, **rami interganglionares**.

All ganglia of the sympathetic trunk give rise to two major types of branches: the *grey rami communicantes*, **rami communicantes grisei** and the *visceral branches* that supply the respective organs.

The grey rami communicantes are the postganglionic fibers that reach the neighboring spinal nerve and run within all its branches. These postganglionic branches provide trophic nerve supply to the muscles and to skin; they also supply the blood and the lymphatic vessels, the sweat and the sebaceous glands, the non-striated muscles and the arrector muscles of hair.

The visceral branches that arise from all ganglia of the sympathetic trunk form the sympathetic nerves that supply the viscera. Some of them comprise the postganglionic fibers only while some feature both postganglionic and preganglionic fibers; the latter traverse the ganglia of sympathetic trunk and synapse within the prevertebral ganglia i.e. directly with the peripheral efferent neurons of the sympathetic part of autonomic nervous system.

The cervical part of sympathetic trunk resides on the deep cervical muscles posterior to the prevertebral layer of cervical fascia. It comprises three ganglia — the superior, the middle and the inferior cervical ganglia.

The *superior cervical ganglion*, **ganglion cervicale superius** is the largest of the group (2X6 mm). It resides anterior the spinous processes of the vertebra C2-C3. It neighbors the internal carotid artery that runs anteriorly and the vagus nerve together with the internal jugular vein that run laterally. The superior cervical ganglion gives rise to two types of branches formed of the postganglionic fibers:

1) the *grey rami communicantes*, **rami communicantes grisei** that join four upper cervical spinal nerves;

2) the visceral branches as follows:

- the *internal carotid nerve*, **nervus caroticus internus** forms the plexus along the internal carotid artery and related branches. The sympathetic fibers from the nerve supply the glands of nasal and palatine mucosa, the lacrimal glands, the eyeball tunics and the *sphincter pupillae*;

- the *external carotid nerves*, **nervi carotici interni** run along the external carotid artery and related branches. They supply the blood vessels, the glands and other cranial organs;
- the *jugular nerve*, **nervus jugularis** ascends along the internal jugular vein to the jugular foramen. There it gives some branches to the ganglia of the glossopharyngeal and the vagus nerves and tot the trunk of the hypoglossal nerve;
- the *laryngopharyngeal branches*, **nervi laryngopharyngei** reach the larynx and the pharynx to form the respective plexuses;
- the *superior cervical cardiac nerve*, **nervus cardiacus cervicalis superior** descends to the thoracic cavity and joins the cardiac plexus.

The *middle cervical ganglion*, **ganglion cervicale medium** is a smaller ganglion (2X2 mm) found at the level of the spinous process of C4. It maintains a specific association with the cervicothoracic (stellate) ganglion via two interganglionic branches that enfold the subclavian artery anteriorly and posteriorly and re-unite below to form the *ansa subclavia* (Lat. Id.). Anteriorly, the ganglion is covered by the common carotid artery and the inferior thyroid artery.

The middle cervical ganglion gives off the branches as follows:

1) the *grey rami communicantes*, **rami communicantes grisei** that join the fifth and the sixth spinal nerves;

2) the visceral branches:

- the *middle cervical cardiac nerve*, **nervus cardiacus cervicalis medius** that descends to the thoracic cavity and joins the cardiac plexus;
- the *inferior thyroid nerve*, **nervus thyroideus inferior** expands along the inferior thyroid artery and related branches to reach the thyroid gland and the larynx;
- the *common carotid nerve*, **nervus caroticus communis** expands along the common carotid artery and proceeds to both external and internal carotid arteries;

In absence of the middle cervical ganglion, all pertaining branches arise from the interganglionic fibers at the level of spinous process of C6.

The *inferior cervical ganglion*, **ganglion cervicale inferius** in most cases merges with the first thoracic ganglion to form the *cervicothoracic (stellate) ganglion*, **ganglion cervicothoracicum (stellatum)**. The ganglion resides at the level of the neck of first rib, posterior to the subclavian and the vertebral arteries. The ganglion gives the branches as follows:

1) the *grey rami communicantes*, **rami communicantes grisei** that join the seventh and the eighth spinal nerves;

2) the visceral branches:

- the *subclavian branches* also given by the ansa subclavia, they form the *subclavian plexus* that reach the thyroid gland, the parathyroid glands, the mediastinal viscera and expand onto the entire upper limb;

- the *vertebral nerve*, **nervus vertebralis** forms the *vertebral plexus*. In the area of the foramen transversarium of C6, there is a small *vertebral ganglion*, **ganglion vertebrale** related to the nerve. the vertebral plexus supplies the blood vessels of the brain and the spinal cord and the meninges;
- the *inferior cervical cardiac nerve*, **nervus cardiacus cervicalis inferior** descends to the thoracic cavity and joins the cardiac plexus together with other cardiac nerves;
- the branches to the vagus nerve and the phrenic nerve.

The thoracic part of sympathetic trunk comprises 10 to 12 *thoracic ganglia*, **ganglia thoracica** situated on the heads of ribs below the parietal pleura. Posteriorly one can distinguish the posterior intercostal arteries and veins. The thoracic ganglia give the following branches:

1) the *grey rami communicantes*, **rami communicantes grisei** that join all thoracic spinal nerves;

2) the visceral branches of upper 5-6 ganglia supply the thoracic viscera:

- the *thoracic cardiac branches*, **rami cardiaci thoracici** arise from upper 5-6 ganglia and join the cardiac plexus;
- the *thoracic pulmonary branches*, **rami pulmonales thoracici** form the *pulmonary plexus*, **plexus pulmonalis** together with the respective branches of the vagus nerve;
- the *esophageal branches*, **rami oesophageales** form the *esophageal plexus*, **pleus oesophagealis** together with the respective branches of the vagus nerve;
- the *thoracic aortic nerves*, **nervi aortic thoracici** form the *thoracic aortic plexus*, **plexus aorticus thoracicus** that expands along all branches of the thoracic aorta.

The visceral branches of the lower 5-6 thoracic ganglia participate in nerve supply of the abdominal viscera:

- the *greater splanchnic nerve*, **nervus splanchnicus major** arises from the ganglia Th5 through Th12. It comprises the preganglionic fibers that merge into a single nerve along the lateral surfaces of vertebral bodies. The nerve penetrates the lumbar part of diaphragm and enters the abdominal cavity to synapse within the coeliac plexus. At the level of Th12 one can distinguish a small *thoracic splanchnic ganglion*, **ganglion thoracicum splanchnicum**. The greater splanchnic nerve also carries the sensory fibers from the lower six thoracic spinal nerves;
- the *lesser splanchnic nerve*, **nervus splanchnicus minor** arises from the ganglia Th10 through Th11. It also comprises the preganglionic fibers. The nerve descends to the abdominal cavity together with the sympathetic trunk (through the lumbar part of diaphragm) and synapses within the coeliac plexus;
- the *least splanchnic nerve*, **nervus splanchnicus imus** arises from the ganglion Th10 and terminates within the renal plexus.

The lumbar part of the sympathetic trunk is a continuation of the thoracic part. It comprises 3 to 5 *lumbar ganglia*, **ganglia lumbales** situated on the anterolateral surfaces of the bodies of lumbar vertebrae next to medial border of the psoas major. The ganglia are covered with the peritoneum. They are associated by means of the interganglionic branches that cross the vertebral column posterior to the aorta and the inferior vena cava.

The lumbar ganglia give rise to two types of branches:

1) the *grey rami communicantes*, **rami communicantes grisei** that join all lumbar spinal nerves;

2) the *lumbar splanchnic nerves*, **nervi splanchnici lumbales** that comprise both pre- and postganglionic fibers from the abdominal aortic plexus. The plexus expands along all branches of abdominal aorta. The preganglionic fibers synapse within the prevertebral ganglia of the abdominal autonomic plexuses.

The sacral part of the sympathetic trunk comprises four *sacral ganglia*, **ganglia sacralia** that reside on the pelvic surface of the sacrum medially from the pelvic sacral foramina. Inferiorly, both trunks merge at a single *ganglion impar* (Lat. Id.) situated on the anterior surface of the first coccygeal vertebra. The sacral ganglia are associated by means of the transverse interganglionic fibers.

The sacral ganglia give rise to the following branches:

1) the *grey rami communicantes*, **rami communicantes grisei** that join all sacral spinal nerves;

2) the *sacral splanchnic nerves*, **nervi splanchnici sacrales** that comprise both pre- and postganglionic fibers given by the superior and the inferior hypogastric plexuses. The fibers of the inferior hypogastric plexus run along all branches of the internal iliac artery to supply the pelvic viscera.

THE AUTONOMIC PLEXUSES

The autonomic plexuses represent network-type arrangement of the peripheral part of autonomic nervous system. The autonomic fibers group around the blood vessels (and form the periarterial plexuses) and around the viscera (and form the visceral plexuses). The plexuses contain both sympathetic and parasympathetic fibers together with the sensory fibers from the vagus nerve and the spinal nerves.

The plexuses contain numerous large and small *autonomic ganglia*, **ganglia autonomica**.

Some of the autonomic plexuses have been already discussed. They are the thoracic aortic plexus, the cardiac plexus, the esophageal plexus and the pulmonary plexus.

The greatest autonomic plexuses reside within the abdominopelvic cavity. The *abdominal aortic plexus*, **plexus aorticus abdominalis** enfolds the abdominal aorta and expands onto both parietal and visceral branches of this great blood vessel.

The greatest portion of the plexus is the *coeliac plexus*, **plexus coeliacus**. Because of size, the plexus is sometimes called the 'abdominal brain'. It

resides on the anterior surface of the aorta next to the coeliac trunk and the superior mesenteric artery. The plexus comprises five large ganglia as follows:

- the *coeliac ganglia*, **ganglia coeliaca**, the crescent-shaped ganglia that enfold the coeliac trunk;
- the *aorticorenal ganglia*, **ganglia aorticorenalia** found next to renal artery arise point;
- the *superior mesenteric ganglion*, **ganglion mesentricum superius** the unpaired ganglion that resides next to the superior mesenteric artery root.

The coeliac plexus comprises both greater and lesser splanchnic nerves that arise from thoracic ganglia of the sympathetic trunk and the lumbar splanchnic nerves given by the respective ganglia. The coeliac plexus accepts the fibers from the posterior vagal trunk (both sensory and parasympathetic) and the sensory fibers from the right phrenic nerve.

The coeliac plexus gives rise to the nerves that carry the postganglionic sympathetic fibers and the preganglionic parasympathetic fibers. The nerves form the periarterial plexuses that run to their responsibility areas i.e. to the viscera.

The second large plexus is the *superior mesenteric plexus*, **plexus mesentericus superior** that runs along all branches of the superior mesenteric artery. The fibers of the plexus supply the small intestine, the cecum, the ascending colon and the transverse colon.

A segment of the abdominal aortic plexus enclosed between the superior and the inferior mesenteric arteries is called the *intermesentric plexus*, **plexus intermesentericus**. This gives rise to the *inferior mesenteric plexus*, **plexus mesentericus inferior** that runs along the artery of the same name and related branches. The fibers of the plexus supply the transverse colon, the descending colon, the sigmoid colon and the upper portion of the rectum.

The abdominal aortic plexus proceeds onto the common iliac arteries to become continuous with left and right *iliac plexuses*, **plexus iliaci**.

Some large nerves from the abdominal aortic plexus form the *superior hypogastric plexus*, **plexus hypogastricus superior**. It resides below the aortic bifurcation between the common iliac arteries. The plexus also accepts the splanchnic nerves from the lower lumbar ganglia and the upper sacral ganglia of the sympathetic trunks.

Within the lesser pelvis, the superior hypogastric plexus splits into left and right *inferior hypogastric plexuses*, **plexus hypogastricus inferior** found laterally from the urinary bladder and the rectum. They also comprise the ganglia and association branches. The inferior hypogastric plexus accepts the sacral splanchnic nerves and the parasympathetic fibers from the *sacral parasympathetic nuclei*, **nuclei parasympathici sacrales**. The inferior hypogastric plexus supplies the pelvic viscera via the respective plexuses (the *superior*, the *middle* and the *inferior rectal plexuses*, the *vesical plexus*, the *prostatic plexus*, the *deferential plexus*, the *uterovaginal plexus* etc.).

THE PARASYMPATHETIC PART, PRAS PARASYMPATHICA

The **cranial part** of the parasympathetic part of autonomic division of CNS is represented with the centers situated within the brainstem and the fibers that join the cranial nerves.

The *accessory nucleus of oculomotor nerve,* **nucleus accessorius nervi oculomotorii** gives rise to the preganglionic fibers that join the *oculomotor nerve* (III pair) and run to the *ciliary ganglion*; the postganglionic fibers reach the *ciliary muscle* and the *sphincter pupillae* as the short ciliary nerves.

The *superior salivatory nucleus,* **nucleus salivatorius superior** gives rise to the fibers related to the facial nerve (VII pair). Some fibers detach from the main trunk to become continuous with the *lesser petrosal nerve.* The nerve passes through the pterygoid canal and terminates within the *pterygopalatine ganglion.* The postganglionic fibers reach the lacrimal gland (via the *zygomatic nerve* and the *lacrimal nerve*), the nasal mucosa (via the *posterior nasal nerves*) and the palatine mucosa (via the *greater* and *lesser palatine nerves*).

Other preganglionic fibers join the *chorda tympani,* which in turn joins the lingual nerve. The preganglionic fibers reach the submandibular ganglion to synapse within it. The postganglionic fibers proceed to the sublingual gland via the *sublingual branches* and to the submandibular gland via the *glandular branches.*

The *inferior salivatory nucleus,* **nucleus salivatorius inferior** gives rise to the fibers that join the *glossopharyngeal nerve* (IX pair). The fibers run as the *tympanic nerve,* which becomes continuous with the *lesser petrosal nerve.* The latter terminates within the *otic ganglion.* The postganglionic fibers join the *auriculotemporal nerve* and reach the parotid gland.

The *dorsal nucleus of vagus nerve,* **nucleus dorsalis nervi vagi** is the greatest parasympathetic nucleus. It resides within the medulla oblongata at the level of the *vagal trigone.* The nucleus gives rise to the preganglionic fibers that reach their responsibility areas alongside with the following branches:

1) the *pharyngeal branches,* **rami pharyngei** participate in formation of the pharyngeal plexus;

2) the *superior laryngeal nerve,* **nervus laryngeus superior** and the *recurrent laryngeal nerve,* **nervus laryngeus recurrens** participate in formation of the laryngeal plexus. The parasympathetic fibers synapse within the laryngeal and the thyroid intramural ganglia;

3) the *superior* and the *inferior cervical cardiac branches,* **rami cardiaci superiores et inferiores** and the *thoracic cardiac branches,* **rami cardiaci thoracici** form the cardiac plexus. The preganglionic fibers synapse within the *cardiac ganglia,* **ganglia cardiaca**;

4) the *bronchial branches,* **rami bronchiales** that take part in formation of the *pulmonary plexus;*

5) the *anterior* and the *posterior gastric branches,* **rami gastrici anteriores et posteriores** that form the *gastric plexus;*

6) the *hepatic branches,* **rami hepatici** that form the *hepatic plexus;*

7) the *coeliac branches,* **rami coeliaci** to the pancreas. These fibers traverse the coeliac plexus and join the *pancreatic plexus;*

8) the *renal branches,* **rami renales** to the kidneys. These fibers terminate within the respective intramural ganglia;

9) the *coeliac branches,* **rami coeliaci** to the small intestine. These fibers traverse the coeliac plexus and join the *superior mesenteric plexus.* On reaching the intestinal wall, they terminate within the ganglia of the *myenteric plexus* (Auerbach's plexus) and the *submucous plexus* (Meissner's plexus);

10) the *coeliac branches,* **rami coeliaci** to the large intestine (except for the sigmoid colon and the rectum). These fibers also traverse the coeliac plexus and join the *superior* and the *inferior mesenteric plexuses* to reach the intestinal wall. There, they terminate within the intramural ganglia.

The **sacral part** of the parasympathetic part of autonomic division of CNS is represented with the *sacral parasympathetic nuclei,* **nuclei parasympathici sacrales**. They reside in between the anterior and the posterior grey columns of spinal cord with respect to the segments S2 through S4.

The cells of these nuclei give rise to the preganglionic fibers that quit the spinal cord within the anterior roots, enter the sacral spinal nerves S2 through S4 and eventually appear within the sacral plexus. The parasympathetic fibers detach from the sacral plexus and run as the *pelvic splanchnic nerves,* **nervi splanchnici pelvici** that join the pelvic autonomic plexuses (the *vesical plexus,* the *prostatic plexus,* the *uterovaginal plexus,* the *middle* and the *inferior rectal plexuses*). These fibers also synapse within the intramural ganglia.

Practice questions

1. What the autonomic division of CNS is responsible for?
2. What are the evolutional features of the autonomic division of CNS?
3. Name the parts of the autonomic division of CNS.
4. Name the chief function of the parasympathetic part of the autonomic division of CNS.
5. Name the chief function of the sympathetic part of the autonomic division of CNS.
6. Where do the centers of the sympathetic part of autonomic division of CNS reside? What are they represented with?
7. Where do the centers of the parasympathetic part of autonomic division of CNS reside?

What are they represented with?
8. Where do the superior autonomic centers reside?
9. Give definition of the preganglionic nerve fibers.
10. Give definition of the postganglionic nerve fibers.
11. Name the groups of the autonomic ganglia.
12. Name the autonomic plexuses of the thoracic cavity.
13. Name the autonomic plexuses of the abdominal cavity.
14. What autonomic (sympathetic) ganglia belong to the coeliac plexus?
15. What autonomic plexuses originate from the coeliac plexus?
16. What are the parts of the intestinal plexus?
17. What plexuses arise from the inferior hypogastric plexus?
18. Give definition of the sympathetic trunk.
19. Give definition of the white rami communicantes.
20. Give definition of the grey rami communicantes.
21. What are the compartments of the sympathetic trunk?
22. Where do the superior, the middle and the inferior cervical ganglia reside?
23. What branches arise from the superior cervical ganglion?
24. What branches arise from the middle cervical ganglion?
25. What branches arise from the inferior cervical ganglion?
26. Where do the thoracic ganglia of sympathetic trunk reside?
27. What branches arise from the thoracic ganglia of the sympathetic trunk?
28. Describe the greater splanchnic nerve.
29. Describe the lesser splanchnic nerve.
30. What branches arise from the lumbar and the sacral ganglia of sympathetic trunk?
31. Describe how the preganglionic sympathetic fibers reach the coeliac plexus.
32. Describe the fate of the postganglionic sympathetic fibers.
33. Describe the route of the preganglionic fibers from the accessory nucleus of oculomotor nerve.
34. Describe the route of the postganglionic fibers from the ciliary ganglion.
35. Describe the route of the preganglionic fibers from the superior salivatory nucleus.
36. Describe the route of the preganglionic fibers from the inferior salivatory nucleus.
37. Describe the route of the postganglionic fibers from the pterygopalatine ganglion.
38. What branches of the vagus nerve supply the viscera?
39. Describe the route of the preganglionic fibers from the sacral parasympathetic nuclei.
40. Name the autonomic plexuses of the pelvic viscera.

THE SENSE ORGANS, ORGANA SENSUUM

The sense organs provide communication between the organism and environment. The stimuli from ambient affect the receptors situated within the receptor shells of the sense organs. They originate from the ectoderm. The sense organs feature auxiliary elements that serve for protection of the receptors, simplify perception and quantify the stimuli. The entire set of the nervous elements that provide perception, conversion of the stimulus into excitation, data encoding and transmission, code parsing and formation of sensation constitutes the analyzer. The receptors generate the nervous impulses transmitted via the nerves and the pathways to the cerebral cortex where they transform into the specific sensation. Thus, the stimuli undergo analysis so the peripheral pats of the sense organs (the eye, the ear, etc) together with the pathways and the respective cortical areas form the analyzer (I.P. Pavlov). There are six types of analyzers as follows:

1) the visual analyzer;
2) the auditory analyzer;
3) the vestibular analyzer;
4) the olfactory analyzer;
5) the gustatory analyzer;
6) the cutaneous analyzer.

The analyzers employ the reflex principle and thus reflect the actual reality.

Three parts of the analyzer

Morphologically, each analyzer features three parts:

1) the *peripheral* receptor part represented either with the receptor cells or with the specialized nerve terminations that accept and transform the stimuli;

2) the *intermediate* transmission part comprises the nerve fibers that conduct the impulses to the cerebral cortex;

3) the *central* cortical end represented with the centers of cerebral cortex. They are responsible for analysis and synthesis of the data acquired. Its work results in shaping of feeling.

Types of receptors

Basing on structural features, the receptors are subdivided into three types:

1) the nervous cell, which features hair or other elements for better perception (the retina, the olfactory cells). these cells are the first neurons of the analyzer pathway;

2) the group of specialized epithelial hair cells that contact with arborized terminations of the sensory neurons (the first neurons of the pathway). These neurons group into the sensory ganglia (the gustatory, auditory and the vestibular receptors);

3) the nerve terminations of various shapes situated between the epithelial cells (cutaneous receptors).

Evolution of the sense organs

The *Colenterata* are the first to develop primitive sense organs. They

appear as special sensory (receptor) cells with more expressed reaction to the stimuli as compared to other ectodermic cells. With evolution progress, the receptor cells concentrate within specific areas like head, mouth or tentacles.

Concentrating within the respective areas, the cells also undergo specialization. Some cells specialize in reception of mechanical (tactile) stimuli, other – in chemical (gustatory) stimuli, etc.

The sense organs develop alongside with the locomotor organs and thus the distant sense organs appear. They provide reaction to stimuli from remote items.

The animals, which develop the auxiliary elements in addition to sensory shells, have more advanced sense organs. The auxiliary elements serve for protection of the receptors, simplify perception and quantify the stimuli. They originate from mesoderm. Evolution of the peripheral parts of analyzers is tightly associated with evolution of the brain and especially the cerebral cortex, which acquires superior parsing centers.

Specific development of sense organs depends on animal's life and environment.

THE EYE AND RELATED STRUCTURES, OCULUS ET STRUCTURAE PERTINENTES

The *visual organ*, **organum visus** occupies the orbit. It comprises the eyeball and the accessory visual structures.

THE EYEBALL, BULBUS OCULI

Related terminology: oculus (Lat.) and **ohpthalmos** (Greek) stand for 'eye'. They give rise to 'ophthalmology' and other terms.

The external features

The spherical eyeball occupies the orbit. The external features of the eyeball are like the following:

- the *anterior pole*, **polus anterior** is the most prominent portion of the cornea;
- the *posterior pole*, **polus posterior** is the most prominent portion opposite to the anterior pole. It resides laterally from the optic nerve;
- the *equator* (Lat. Id.) the line that crosses the eyeball in between the poles. It separates the eyeball into the anterior and the posterior parts;
- the *meridians*, **meridiani** are the lines that encircle the eyeball. They join the poles;
- the *external axis of eyeball*, **axis bulbi externus** is an imaginary longitudinal line that runs through both poles (24 mm long);
- the *internal axis of eyeball*, **axis bulbi internus** is a portion of the external axis that expands between the internal surface of cornea and the retina (21.5 mm long);

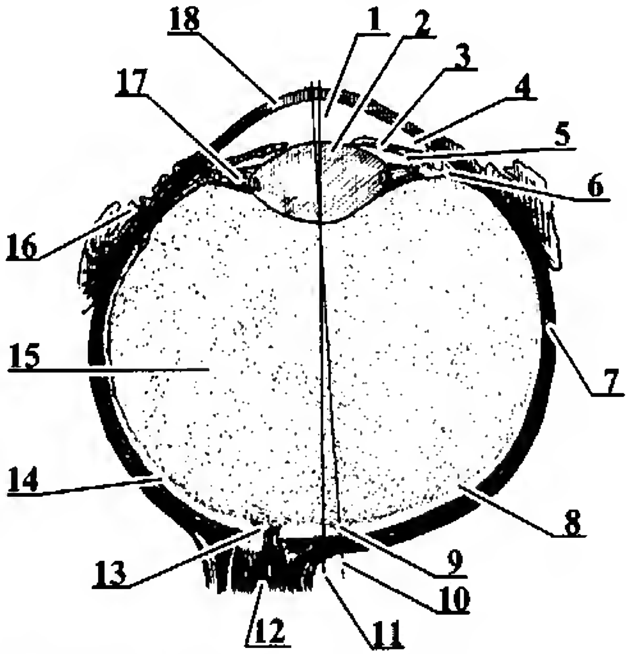


Fig. 54. Horizontal section of eye (scheme). 1 — camera anterior; 2 — lens; 3 — iris; 4 — angulus iridocornealis; 5 — camera posterior; 6 — corpus ciliare; 7 — sclera; 8 — retina; 9 — fovea centralis; 10 — axis opticus; 11 — axis bulbi externus; 12 — n. opticus; 13 — discus n. optici; 14 — choroidea; 15 — corpus vitreum; 16 — conjunctiva; 17 — zonula ciliaris; 18 — cornea.

- the *optic axis*, **axis opticus** is an imaginary line that corresponds to the route of light rays from the cornea to the *fovea centralis*;
- the *anterior segment*, **segmentum anterius**;
- the *posterior segment*, **segmentum posterius**.

The eyeball comprises the capsule and the nucleus (the internal media) (Fig. 54).

The capsule consists of the fibrous layer, the vascular layer and the inner layer (the retina).

The *fibrous layer of eyeball*, tunica fibrosa bulbi

The fibrous layer of eyeball is the external tunic. It comprises two portions: the sclera and the cornea.

The *sclera* (Lat. Id.) is an opaque white posterior (4/5 of the entire layer) portion of the fibrous layer. The sclera and the cornea are delimited by the *sulcus sclerae* (Lat. Id.). Deeper in this area, one can distinguish a circular *scleral venous sinus*, **sinus venosus sclerae**[1]. Its anterior portion is covered with the conjunctiva formed of

[1] the canal of Schlemm

the connective tissue and multilayer epithelium. The rest of the sclera is covered with endothelium.

The *cornea* (Lat. Id.) is an anterior translucent portion of the layer. It consists of avascular connective tissue covered with epithelium on both sides.

The *vascular layer of eyeball*, **tunica vasculosa bulbi**

The vascular layer is the middle tunic of eyeball. It comprises the choroid, the ciliary body and the iris. It features numerous blood vessels responsible for blood supply of the retina and for production of aqueous humor.

The *choroid*, **choroidea** is the larger posterior portion of the layer. It consists of a thin layer of connective tissue with embedded blood vessels and pigment cells. A slit-like space formed because of loose connection between the choroid and the sclera is called the *perichoroidal space*, **spatium perichoroidale**.

The *ciliary body*, **corpus ciliare** is the anterior thicker portion of the vascular layer that enfolds the lens. Anteriorly, the ciliary body becomes continuous with the iris, posteriorly — with the choroid. The ciliary body features the ciliary muscle and the ciliary processes:

- the *ciliary muscle*, **musculus ciliaris** consists of smooth muscle fibers. The fibers are the meridional, the longitudinal, the radial and the circular. The muscle serves for accommodation;
- the *ciliary processes*, **processus ciliares** reside on the inner surface of ciliary body (about 70-80 are distinguishable). They are arranged radially and feature abundant blood capillaries.

The *iris* (Lat. Id.) is a visible anterior portion of the vascular layer. It features a central opening called *pupil*, **pupilla**[1]. By narrowing or dilating, the pupil regulates light exposure of the retina. The *ciliary margin*, **margo ciliaris** attaches to the ciliary body and the *pupillary margin*, **margo pupillaris** encircles the pupil. A junction between the cornea and the iris features the pectinate ligament with the slit-like spaces. The iris contains the pigmented cells[2] and smooth muscles as follows:

- the *sphincter pupillae*, **musculus sphincter pupillae** is formed of circular muscle fibers that surround the pupil. The muscle narrows the pupil;
- the *dilator pupillae*, **musculus dilatator pupillae** is formed of radial muscle fibers. The muscle dilates the pupil.

The *inner layer of eyeball*, **tunica interna bulbi**

The inner layer of eyeball is represented with the *retina* (Lat. Id.) with the following parts distinguishable:

[1] a diminutive from Latin 'pupa' — the puppet, because one can see his diminished reflection in the eyes of vis-a-vis
[2] this pigment specifies the color of iris

- the *optic part of retina*, **pars optica** is the posterior larger portion adherent to the choroid. Anteriorly, it terminates with the *ora serrata* (Lat. Id.). The optic part features two layers:

a) the *pigmented layer*, **stratum pigmentosum** is the outer layer formed of pigmented cells;

b) the *neural* layer, **stratum nervosum** is the inner translucent layer that contains the receptor cells — the rods and the cones. The cones work in bright illumination and serve for color vision. They are the daylight receptors. The rods work in twilight, they are the night receptors;

- the *nonvisual retina*, **pars caeca retinae** comprises only pigmented cells and epithelium. It has no receptor cells. The nonvisual retina has the parts as follows:

a) the *ciliary part of retina*, **pars ciliaris retinae** invests the ciliary body;

b) the *irideal part of retina*, **pars iridica retinae** invests the iris. Both parts lack the receptor cells.

The optic part of retina

This part is well visible via the ophthalmoscope as deep red area. The portion related to the posterior pole contains the *optic disc*, **discus nervi optici** (1.7 mm of diameter) — the escape point of the optic nerve[1]. In the center of the disc, one can distinguish the *depression of optic disc*, **excavatio disci** that passes the *central retinal artery*.

Laterally from the optic disc (about 4 mm away), one can see the *macula*, **macula lutea** (1 mm of diameter) with featured *fovea centralis* (Lat. Id.).

This is the focus point of retina and thus constitutes the area of best vision acuity.

The internal media of eyeball

The internal media of eyeball comprise the lens and the chambers (the latter contain the aqueous humor and the vitreous body).

The *lens*, lens

The lens is a translucent body, which resembles the double convex lens. Its antero-posterior size equals 4 mm and the diameter — 9 mm. It consists of resilient translucent fibers and has no blood vessels. The central harder portion of the lens is called the nucleus and the softer peripheral portion — the cortex. The lens is enfolded into amorphous *capsule of lens*, **capsula lentis**. The capsule attaches to the ciliary body by means of the *ciliary zonule*, **zonila ciliaris**[2]. The spaces between the zonular fibers — the *zonular spaces*, **spatia zonularia**[3] open into the posterior chamber (Fig. 55).

[1] the blind spot called so because it has no receptor cells
[2] the ligament of Zinn
[3] spaces of Petit

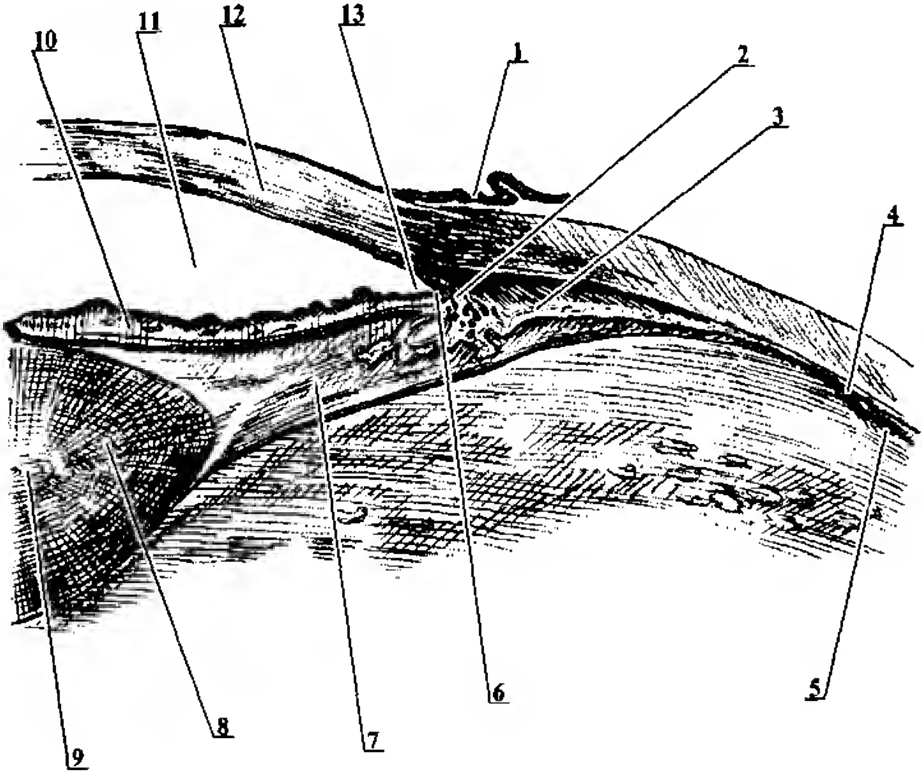


Fig. 55. The anterior part of eyeball (horizontal section). 1 – conjunctiva; 2 – sinus venosus sclerae; 3 – m. ciliaris; 4 – ora serrata; 5 – retina; 6 – spatia anguli iridocornealis; 7 – zonula ciliaris; 8 – lens; 9 – nucleus lentis; 10 – iris; 11 – camera anterior; 12 – cornea; 13 – angulus iridocornealis.

The chambers of eyeball

The *anterior chamber*, **camera anterior bulbi** is bounded by the posterior surface of cornea anteriorly and the anterior surface of iris posteriorly. It communicates with the posterior chamber via the pupil. The junction of the cornea and the iris constitutes the *iridocorneal angle*, **angulus iridocornealis**. Here, the conjunctival fibers form numerous septa that interlace to appear as the *trabecular tissue*, **reticulum trabeculare** (the *pectinate ligament*, **ligamentum pectinatum**). The spaces between the septa are the endothelium-lined *spaces of iridocorneal angle*, **spatia anguli iridocornealis**[1]. The spaces communicate with the scleral venous sinus.

[1] the spaces of Fontana

The *posterior chamber*, **camera posterior bulbi** is bounded by the posterior surface of iris anteriorly and the lens with featured ciliary zonule posteriorly. The posterior chamber communicates with the zonular spaces and the anterior chamber.

Both anterior and posterior chambers are filled with clear fluid called the *aqueous humor*, **humor aquosus**.

The *vitreous (postremal) chamber*, **camera vitrea (postrema) bulbi** is a larger cavity found posterior to the lens. It is filled with translucent *vitreous body*, **corpus vitreum**. The latter appears as jelly-like substance enfolded into a thin capsule. Anteriorly one can distinguish the *hyaloid fossa*, **fossa hyaloidea** that houses the lens.

Circulation of aqueous humor

The aqueous humor is continuously produced by the capillaries of the ciliary processes. The humor fills the *zonular spaces*, **spatia zonularia** from where it proceeds to the chambers. The humor drains to the bloodstream via the *spaces of iridocorneal angle*, **spatia anguli iridocornealis** and further to the *scleral venous sinus*, **sinus venosus sclerae**. The sinus communicates with the scleral veins. This process ensures constant pressure (ocular tension) within the eyeball (in order to maintain a certain shape). Drainage disorders result in severe disease — the glaucoma, which may cause vision acuity loss or even complete blindness.

The refractive media of eyeball

When passing through the eyeball, the light beams refract and focus on the *fovea centralis* of retina. The refractive media of the eyeball are: 1) the cornea, 2) the aqueous humor, 3) the lens and 4) the vitreous body.

Clinical applications

Mismatched refraction and internal axis length cause the light rays focus either anterior to the focus point (myopia or shortsightedness) or somewhat behind it (hyperopia or far-sightedness). Both states can be corrected by means of spectacles or contact lenses.

Accommodation

When viewing remote objects, the ciliary muscle relaxes and the internal media exert a certain pressure on the layer. The ciliary zonule thus appears to be stretched, which in turn results in flattening of the lens (up to 3.7 mm) because of radial stretching of its capsule.

On the contrary, watching the close objects causes the ciliary muscle to contract and it pulls the ciliary body together with the entire vascular layer anteriorly. Circular fibers of the ciliary muscle narrow the opening of the ciliary body where the lens is suspended. This all reduces tension of the *ciliary zonule* and the capsule of lens. The lens thus appears to be convex (up to 4.4 mm). These two opposing processes are called accommodation. With aging, the lens loses resilience and the *ciliary muscle* undergoes partial atrophy. This results in accommodation disorders and vision acuity loss.

THE ACCESSORY VISUAL STRUCTURES, STRUCTURAE OCULUS ACCESSORIA

The accessory visual structures are the extra-ocular muscles, the orbital fascia, the eyebrows, the eyelids, the conjunctiva and the lacrimal apparatus.

The *extra-ocular muscles*, musculi externi bulbi oculi

The extra-ocular muscles are four rectus muscles, two oblique muscles and the levator palpebrae superioris. All muscles (except for the inferior oblique) arise from the *common tendinous ring* in the area of optic canal and attach to the sclera (Fig. 56).

The rectus muscles:

- the *superior rectus*, **musculus rectus superior** rotates the eyeball superiorly; nerve supply — the oculomotor nerve;
- the *inferior rectus*, **musculus rectus inferior** rotates the eyeball inferiorly; nerve supply — the oculomotor nerve;
- the *medial rectus*, **musculus rectus medialis** rotates the eyeball medi-

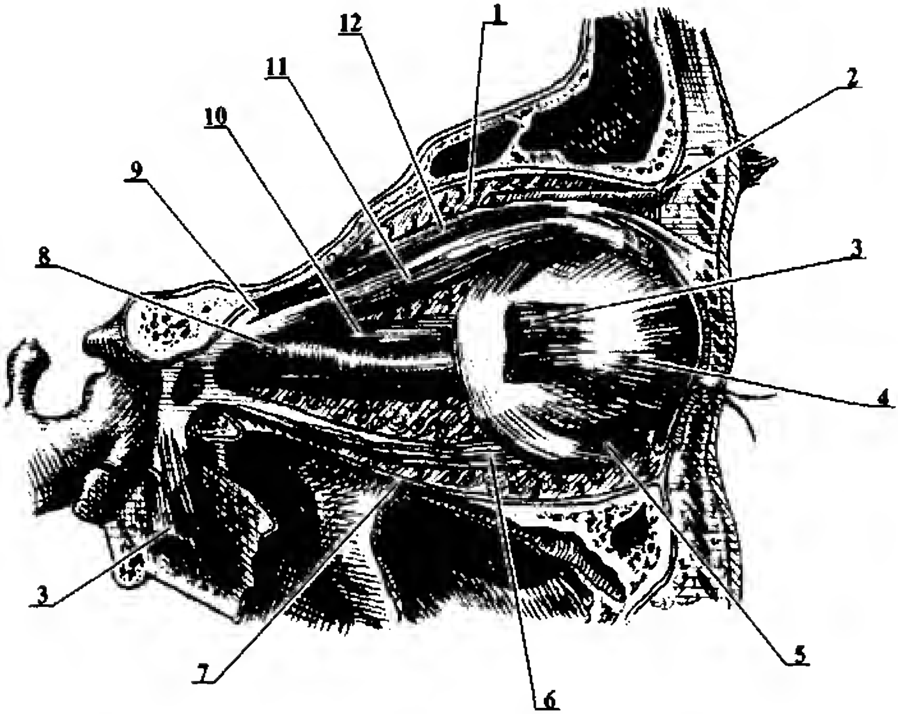


Fig. 56. The extrinsic muscles of eyeball. 1 — corpus adiposum orbitae; 2 — n. trochlearis; 3 — m. rectus lateralis; 4 — sclera; 5 — m. obliquus inferior; 6 — m. rectus inferior; 7 — periorbita; 8 — n. opticus; 9 — anulus tendineus communis; 10 — m. obliquus superior; 11 — m. rectus superior; 12 — m. levator palpebrae superior.

ally; nerve supply — the oculomotor nerve;

- the *lateral rectus*, **musculus rectus lateralis** rotates the eyeball laterally; nerve supply — the abducent nerve.

The oblique muscles

- the *superior oblique*, **musculus obliquus superior** initially runs anteriorly along the medial wall of orbit. Its tendon loops around the *trochlea* (Lat. Id.) and proceeds in posterolateral direction. The muscle attaches to the superolateral side of the eyeball posterior to equator. Action: the muscle rotates the eyeball inferiorly and laterally; nerve supply — the trochlear nerve;
- the *inferior oblique*, **musculus obliquus inferior** arises from the medial portion of orbital wall. The muscle runs upwards and attaches to the lateral side of the orbit posterior to the equator. Action: the muscle rotates the eyeball superiorly and laterally; nerve supply — the oculomotor nerve.

The *levator palpebrae superioris*, **musculus levator palpebrae superioris** arises from the common tendinous ring. The muscle runs above the superior rectus and inserts into skin of superior eyelid. Action: the muscle elevates the superior eyelid.

The *fasciae of orbit*, fasciae orbitae

The eyeball does not fully fit the orbit. It is separated from the orbital walls by the muscles and fat tissue called the *retorobulbar fat*, **corpus adiposum orbitae**[1]. The retrobulbar fat is separated from the eyeball by dense connective tissue tunic (the Tenon's capsule) called the *fascial sheath of eyeball*, **vagina bulbi**.

The contacting surfaces of the fascial sheath and the eyeball fuse by means of thin connective tissue fibers. This *episcleral space* is filled with fluid that allows free rotation of an eyeball similar to ball-and-socket joint.

Anteriorly, the orbit is closed by the *orbital septum*, **septum orbitae** that attaches to the eyelids.

The *eyelids*, **palpebrae** appear as skin plates that easily close and cover the eyeball (Fig. 57).

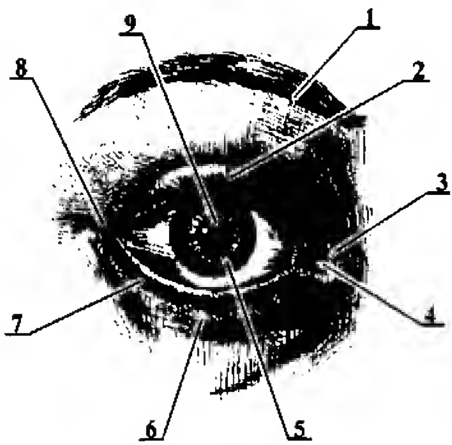


Fig. 57. The exterior of eye. 1 — supercilium; 2 — palpebra superior; 3 — comissura medialis palpebrarum; 4 — caruncula lacrimalis; 5 — iris; 6 — palpebra inferior; 7 — cilia; 8 — comissura lateralis palpebrarum; 9 — pupilla.

[1] an elastic layer that serves for shock absorption

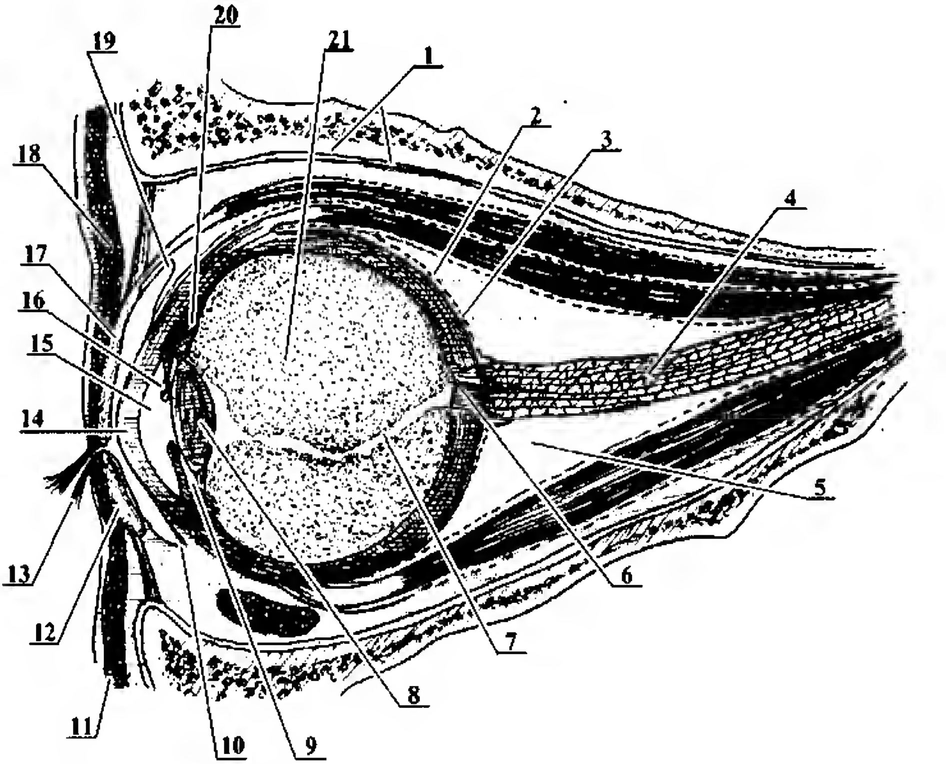


Fig. 58. Sagittal section of the orbit. 1 – periorbita; 2 – vagina bulbi; 3 – spatium episclerale; 4 – n. opticus; 5 – corpus adiposum orbitae; 6 – discus n. optici; 7 – canalis hyaloidues; 8 – lens; 9 – camera posterior; 10 – fornix conjunctivae inferior; 11 – septum orbitale; 12 – tarsus inferior; 13 – cilii; 14 – cornea; 15 – camera anterior; 16 – iris; 17 – tarsus superior; 18 – pars palpebralis m. orbicularis oculi; 19 – fornix conjunctivae superior; 20 – corpus ciliare; 21 – corpus vitreum.

The *superior* and *inferior eyelids*, **palpebrae superior et inferior** delimit the *palpebral fissure*, **rima palpebrarum**. Above the upper eyelid, one can see the *eyebrow*, **supercilium**. The eyelids are covered with skin from outside and the conjunctiva from inside. The eyelids have the feature as follows:

- the *superior* and *inferior tarsus*, **tarsus superior et inferior** are the dense connective tissue plates that form the eyelids core;
- the *anterior* and *posterior margins*, **limbi palpebrales superior et inferior** with featured *eyelashes*, **cilii**;
- the *lateral* and *medial palpebral commissures*, **comissurae palpebrarum lateralis et medialis** are the points where the two eyelids meet;

- the *lateral* and *medial palpebral ligaments*, **ligamenta palpebrarum lateralis et medialis** attach the tarsi to the orbital margins;
- the *tarsal glands*, **glandulae tarsales** lubricate the palpebral margins;
- the *ciliary glands*, **glandulae ciliares**;
- the *sebaceous glands*, **glandulae sebaceae**;
- the *superior* and *inferior tarsal muscles*, **musculus tarsalis superior et inferior** are the muscles related to the tarsi.

The *conjunctiva*, **tunica conjunctiva**

The conjunctiva is a thin epithelium-invested connective tissue tunic that resembles the mucosa. It covers the internal surfaces of the eyelids and the anterior portion of the eyeball (except for the cornea) (Fig. 58). The conjunctiva has the parts and the features as follows:

- the *palpebral conjunctiva*, **tunica conjunctiva palpebrarum** covers the eyelids from inside;
- the *bulbar conjunctiva*, **tunica conjunctiva bulbi** covers the anterior portion of the eyeball;
- the *superior* and *inferior fornices*, **fornics conjunctivae superior et inferior** appear where the palpebral conjunctiva becomes continuous with the bulbar conjunctiva;
- the *conjunctival sac*, **saccus conjunctivalis** is a slit-like cavity formed of the palpebral and the orbital conjunctivae. The sac contains the lacrimal fluid. With the eyelids closed, the sac becomes closed;
- the *conjunctival glands*, **glandulae conjunctivales**.

The lacrimal apparatus, apparatus lacrimalis

The lacrimal apparatus (Fig. 59) is represented with the lacrimal gland and the drainage ducts:

- the *lacrimal gland*, **glandula lacrimalis** resides within the *fossa for lacrimal gland* in the superolateral angle of orbit. The gland features the *excretory ducts*, **ductuli excretorii** (10-12) that open into the *lacrimal sac*, **saccus lacimalis** (into the lateral portion of the superior lacrimal fornix); the lacrimal fluid moistens the eyeball and eventually appears in the medial angle of eye;
- the *lacrimal caruncle*, **caruncula lacrimalis** is a pink small eminence in the medial angle of eye. The area around the caruncle is called the *lacrimal lacus (lake)*, **lacus lacrimalis**;
- the *superior* and *inferior lacrimal canaliculi*, **canaliculi lacrimales superior et inferior** begin with the openings called the *lacrimal punctums*, **punctum lacrimale**, that reside on the eyelids; the canaliculi run below the palpebral skin and open into the lacrimal sac;
- the *lacrimal sac*, **saccus lacrimalis** resides within the *fossa for lacrimal sac* (it's in the lower portion of the medial orbital wall);

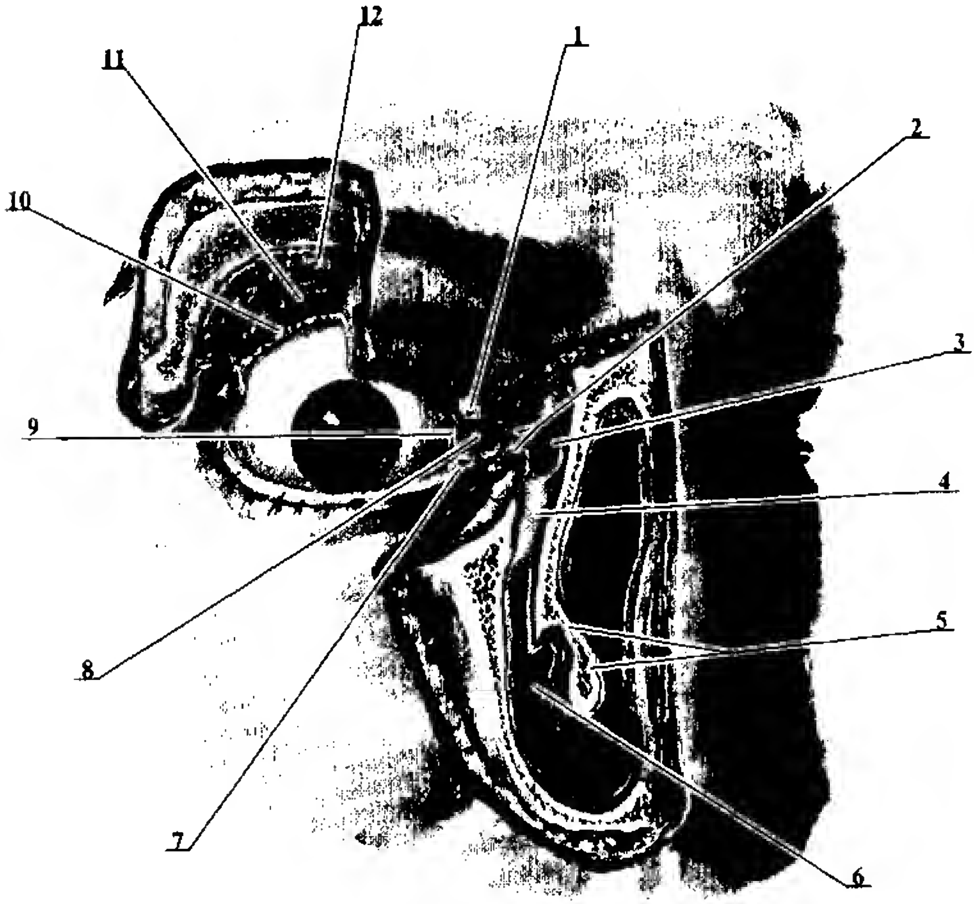


Fig. 59. The lacrimal apparatus. 1 — papilla lacrimalis et punctum lacrimalis superior; 2 — canaliculi lacrimales; 3 — saccus lacrimalis; 4 — ductus nasolacrimalis; 5 — concha nasalis inferior; 6 — meatus nasi inferior; 7 — papilla lacrimalis et punctum lacrimalis inferior; 9 — plica semilunaris; 10 — ductuli excretorii; 11 — pars palpebralis glandulae lacrimalis; 12 — pars orbitalis glandulae lacrimalis.

- the *nasolacrimal duct*, **ductus nasolacrimalis** is an inferior continuation of the lacrimal sac. It runs within the nasolacrimal canal to open into the inferior nasal meatus.

THE PATHWAYS OF THE VISUAL ANALYZER

a) The *retina* comprises three linked layers of the nerve cells that accept light stimuli and transmit them to the brain:

1) the rods and the cones are the specialized receptor cells situated within the outer layer of the retina;

a) the cones (6.5 million cells) mostly occupy the area of the *macula*. They are responsible for vision acuity and color reception;

b) the rods (125 million cells) are scattered all around the retina. They are responsible for scattered light reception, peripheral vision and night vision;

2) the bipolar neurons form the middle layer of the retina. Their peripheral processes synapse with the receptor cells and the central processes — with the multipolar cells of next layer;

3) the ganglionic neurons occupy the internal layer of retina. Their dendrites synapse with the central processes of bipolar neurons and the axons run to the optic disc area. There, they join to form the optic nerve. The optic nerve penetrates the tunics of the eyeball and becomes evident around the posterior pole.

b) The optic nerve and the optic tract

1) the *optic nerve*, **nervus opticus** (the second pair) escapes the orbit via the *optic canal*; within the middle cranial fossa it forms the optic chiasm situated anterior to the sella turcica;

2) the *optic chiasm*, **chiasma optica** is an incomplete decussation because the fibers that arise from the lateral halves of both retinas remain non-decussated and proceed to the optic tract on the respective side;

3) the *optic tract*, **tractus opticus** is a continuation of the optic chiasm. It comprises both decussated and non-decussated fibers (from medial and lateral portion of each retina respectively)[1]. Each tract loops around the cerebral peduncle and terminates within the subcortical visual centers (the lateral geniculate body, the pulvinar of thalamus and the superior colliculi of tectal plate).

c) the subcortical and cortical visual centers

1) the *lateral geniculate body*, **corpus geniculatum laterale** is a part of thalamus. It belongs to the metathalamus;

2) the *pulvinar*, **pulvinar thalami** is a posterior portion of the dorsal thalamus;

3) the *superior colliculi*, **colliculi superiores** of the tectal plate are associated with the spinal cord (the

[1] injury to the optic tract results in lateral vision field loss for ipsilateral eye and medial vision field loss for contralateral eye

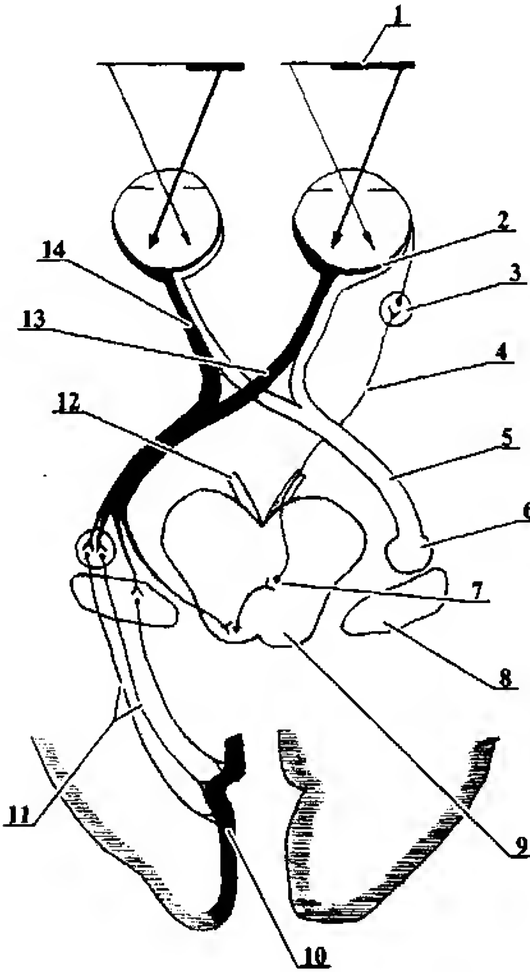


Fig. 60. The visual pathways. 1 — visus oculi; 2 — retina; 3 — gangl. ciliare; 4 — radix oculomotorius; 5 — tractus opticus; 6 — corpus geniculatum laterale; 7 — nucl. accessorius n. oculomotirii; 8 — pulvinar thalami; 9 — colliculi superiores; 10 — sulcus calcarinus; 11 — radiatio optica; 12 — n. oculomotorius; 13 — chiasma opticum; 14 — tractus opticus.

tectospinal tract) and with the *accessory nucleus of oculomotor nerve,* **nucleus accessorius nervi oculomotorii.** The latter is responsible for pupillary reflex and accommodation.

The fibers given by the lateral geniculate body traverse the posterior limb of the internal capsule and fan out to form the *optic radiation,* **radiatio optica.** These fibers terminate within the marginal portion of each

calcarine sulcus (the visual cortex of the occipital lobe). The cortex is responsible for development of visual sensations and their analysis.

EVOLUTION OF VISUAL ORGANS

Visual organs in invertebrates

The primal visual organs are the photosensitive cells scattered diffusely in the ectoderm. With evolution progress, the photosensitive cells concentrate in certain areas within the fossa or the cups and acquire dark pigment trimming.

Further evolution of the visual organs in invertebrates takes complex and various routes as evident in formation of vesicular eyes, lenses, cornea and other accessory structures. Some species develop complex facet eyes from separate simple eyes (the *Crustacea* or the insects).

Evolution of visual organs in vertebrates

In vertebrates, the visual organs developed in the way different to that of the invertebrates. Here, the visual organs developed together with the nervous system. The hypothetical progenitors of the vertebrates are believed to have the entire nervous system built up of the photosensitive cells. In lancelets, such cells persist around the central canal of the neural tube thus making the nervous system retain photosensitivity.

With relative body enlargement and resulting transparency loss, the photosensitive portion of the neural tube evaginates to get closer to the ectoderm. The primal eye acquires the tunics, the lens, the special muscles and other accessory structures. The neural tissue gives rise to the photosensitive tunic (the retina) that comprises true photosensitive nerve cells.

The fish feature flat cornea and rounded lens moved by a special muscle. The reptiles and the birds develop well visible ciliary muscle, which is able to alter lens convexity (the accommodation muscle). Some vertebrates feature movable eyelids, the lacrimal apparatus and other accessory elements.

DEVELOPMENT OF EYES IN HUMANS

Formation of the eye primordium from evaginated lateral walls of the prosencephalon

The most important event of the eye development is formation of its photosensitive part – the retina – from evagination of the prosencephalon (the diencephalon). This results in formation of the optic vesicle, which communicates freely with the cerebral vesicle cavity. The optic vesicle becomes evident at the third week of development. The external wall of the vesicle neighbors the ectoderm.

Formation of the optic cup

As the embryo grows, the wall of the optic vesicle invaginates to form the double-layer optic cup. The latter maintains association with the brain

by means of the optic stalk. The external wall of the cup grows thinner and eventually transforms into the pigmented layer of retina. The internal layer on the contrary grows thicker and gives rise to the neural layer of retina with featured layers of neurons. The axons of ganglionic cells grow in direction of the optic stalk and quit the vesicle as the optic nerve.

Formation of the lens

The lens develops from the ectoderm adherent to the optic cup. A small vesicle that gives rise to the lens detaches from the ectoderm and incorporates into the optic cup. Further on, the lens cavity collapses and the primordial cells transform into the translucent fibers.

Formation of the choroid

The choroid develops from the mesenchymal cells that incorporate into the cup. The blood vessels that enter the optic cup together with the mesenchyme give rise to the *hyaloid artery*, **arteria hyaloidea** that supplies the lens. Later on, the artery and related vascular network disappear. Within the cavity of the cup, one can distinguish a jelly-like substance – a future vitreous body.

Formation of the sclera and the cornea

The sclera develops from the mesenchyme that surrounds the optic cup. This area features intense growth of scaffold connective tissue. The anterior portion of sclera transforms into the cornea; most part of it originates from mesenchyme yet the outer layer is of ectodermic origin.

The accessory visual structures begin developing at the third month of embryonic development.

THE EAR, AURIS

The auditory analyzer comprises the external ear, the middle ear and the internal ear.

THE EXTERNAL EAR, AURIS EXTERNA

The external ear comprises the auricle and the external acoustic meatus.

The *auricle*, **auricula** features a cartilaginous framework called the *auricular cartilage*, **cartilago auriculae**. The cartilage is covered with skin (Fig. 60). The inferior portion of the auricle – *lobule of auricle*, **lobulus auricilae** features fat tissue instead of cartilage. Unlike the animals, the humans have no ability of directed sound capturing, so the human auricle is small and the muscles featured are rudimentary. The auricle features the parts as follows:

- the *lobule of ear*, **lobulus auriculae** is the lower cartilage-devoid portion;
- the *helix* (Lat. Id.) is a thickened curved rim of the auricle;
- the *antehelix* (Lat. Id) is the eminence similar to the helix found

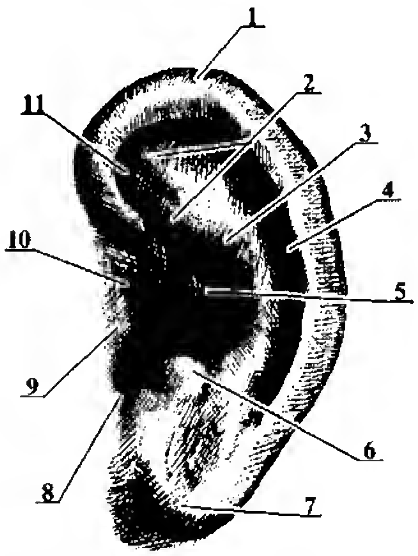


Fig. 61. The auricle. 1 — helix; 2 — antihelix; 3 — crura antihelicis; 4 — scapha; 5 — crus helicis; 6 — antitragus; 7 — lobulus auriculare; 8 — incisura intertragica; 9 — tragus; 10 — meatus acusticus externus; 11 — fossa triangularis.

anterior to the latter; it bounds the auricular cavity posteriorly;

- the *scapha* (Lat. Id.) is the excavation bounded by the helix and the antehelix;
- the *concha of auricle,* **concha auriculae** is the deep excavation bounded by the antehelix; the concha leads to the external acoustic opening;
- the *tragus* (Lat. Id.) is the eminence situated anterior to the external acoustic opening;
- the *antitragus* (Lat. Id.) a smaller eminence situated opposite to the tragus;
- the *anterior notch,* **incisura anterior**;
- the *intertragic notch,* **incisura intertragica**;
- the *posterior auricular groove,* **sulcus posterior auriculae**;
- the *isthmus of cartilaginous auricle,* **isthmus cartilaginis auricularis**;
- the *terminal notch of auricle,* **incisura terminalis auricularis**;
- the *fossa antihelica* (Lat. Id.);
- the *eminentia conchae* (Lat. Id.);
- the *eminentia scaphae* (Lat. Id.);
- the *eminentia fossae triangularis* (Lat. Id.).

The auricle attaches to the skull by means of the ligaments. It also features rudimentary muscles.

The *external acoustic meatus,* **meatus acusticus externus** consists of the cartilaginous (1/3) and the bony (2/3) parts. The meatus is 30-32 mm long and 6-9 mm wide. The meatus is invested with the skin with featured hair and glands. The meatus terminates at the tympanic membrane that delimits the external and the middle ears (Fig. 62). The external surface of the membrane is invested with a thin layer of squamous epithelium and the internal surface — with the simple cuboidal epithelium, which belongs to the epithelial investment of the middle ear. The elliptic tympanic membrane is 11 mm long and 9 mm wide. The external acoustic meatus appears as S-shaped tube with the curvatures related to both horizontal and frontal planes[1].

[1] examination of the tympanic membrane requires the ear to be retracted superiorly and posteriorly

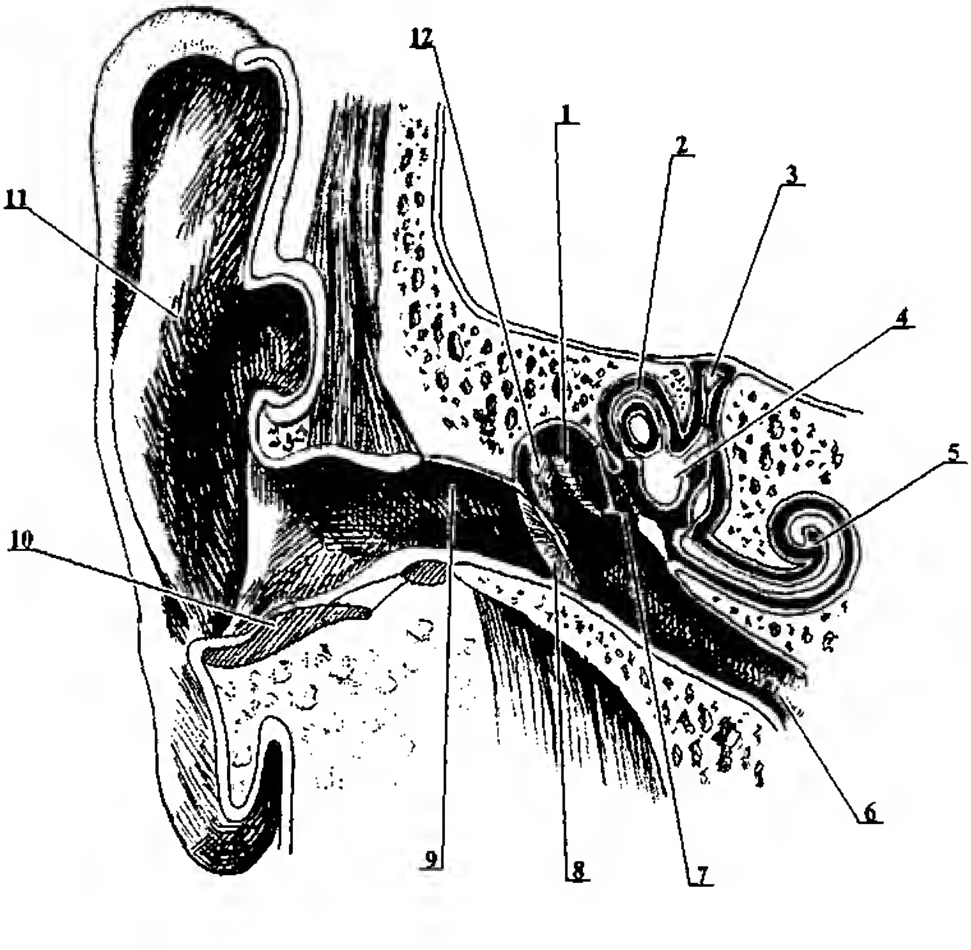


Fig. 62. Frontal section of ear. 1 — incus; 2 — canales semicirculares; 3 — saccus endolymphaticus; 4 — vestibulum; 5 — ductus cochlearis; 6 — tuba auditiva; 7 — stapes; 8 — membrana tympanica; 9 — meatus acusticus externus; 10 — cartilago meatus acustici externi; 11 — auricula; 12 — malleus.

THE MIDDLE EAR, AURIS MEDIA

The middle ear comprises the tympanic cavity with the auditory ossicles and the pharyngotympanic (auditory) tube[1]. The middle ear is delimited from the external ear by the tympanic membrane.

The *tympanic membrane*, membrana tympanica

The tympanic membrane is the elastic oval plate (9x11 mm) that seals the opening in the lateral wall of the tympanic cavity (Fig. 63).

The membrane tilts medially so that it forms a sharp angle with the in-

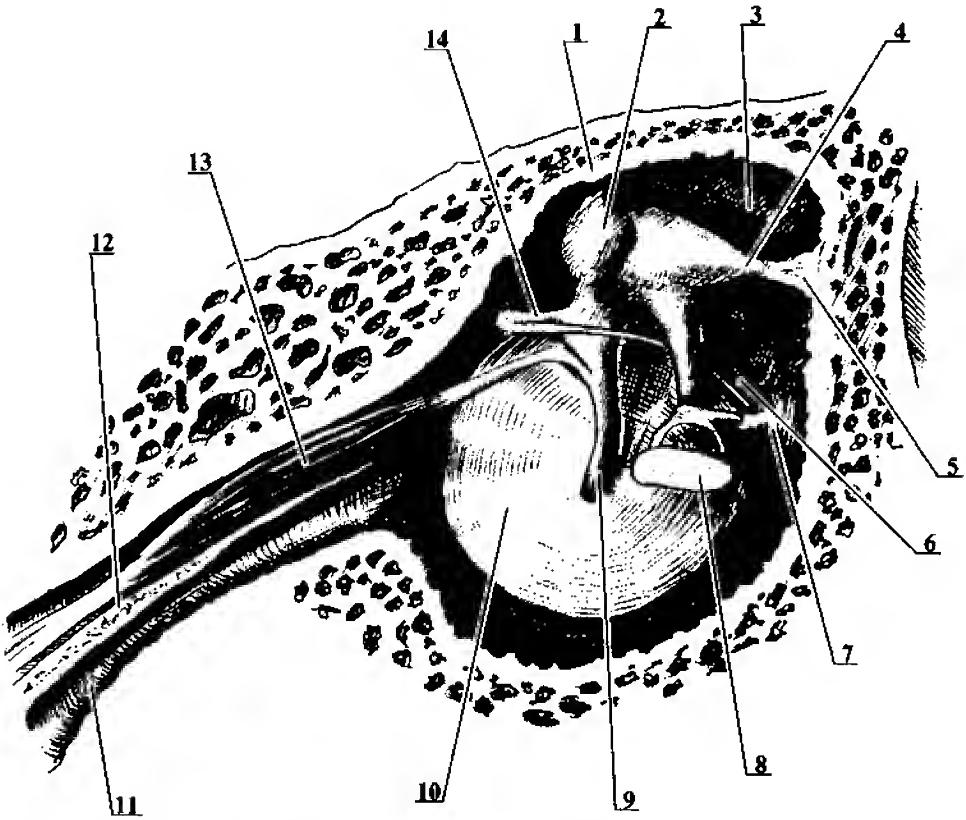


Fig. 63. The internal surface of tympanic membrane. 1 — lig. mallei; 2 — caput mallei; 3 — recessus epitympanicus; 4 — incus; 5 — lig. incudis; 6 — chorda tympani; 7 — eminentia pyramidalis; 8 — stapes; 9 — manubrium mallei; 10 — membrana tympanica; 11 — pars ossea tubae auditivae; 12 — septum canalis musculotubarii; 13 — m. tensor tympani; 14 — lig. mallei anterius.

[1] the Eustachian tube

ferior wall of the tympanic cavity. The membrane is formed of the fibrous tissue. Its outer surface is covered with skin, while the inner surface features the same investment as the tympanic cavity.

The parts of the tympanic membrane:

- the *pars tensa* (Lat. Id.) is the larger (3/4) tense portion of the membrane attached firmly to the margins of the external acoustic opening. It consists of resilient fibrous tissue;
- the *pars flaccida* (Lat. Id.) is the smaller (1/4) loose portion of the membrane. It lacks fibrous tissue;
- the *umbo of tympanic membrane*, **umbo membranae tympanicae** is the central funnel-shaped excavation of the membrane.

The *tympanic cavity*, **cavitas tympani**

The tympanic cavity is the air-filled cavity of irregular shape situated within the petrous part of temporal bone. Its volume is about 1 cubic centimeter. The cavity is invested with the mucous membrane.

The walls of the tympanic cavity

The tympanic cavity has six walls as follows:

1) the *tegmental wall*, **paries tegmentalis** is the wall related to the *tegmen tympani* — a thin bony plate of the petrous part of temporal bone;

2) the *jugular wall (the floor)*, **paries jugularis** is the wall related to the jugular fossa;

3) the *labyrinthine wall*, **paries labyrinthicum** is the medial wall related to the bony labyrinth. It features the *promontory*, **promontorium** and the openings like the following:

- the *oval window*, **fenestra vestibuli** situated above the promontory. The window articulates with the base of stapes;
- the *round window*, **fenestra cochleae** a smaller opening situated below the promontory. It is sealed with the *secondary tympanic membrane*, **membrana tympanica secundaria;**

4) the *membranous wall*, **paries membranaceus** is a small lateral wall sealed with the tympanic membrane. An extension of the tympanic cavity above the tympanic membrane is called the *epitympanic recess*, **recessus epitympanicus**;

5) the *carotid wall*, **paries caroticus** is the wall related to the carotid canal. On the wall one can distinguish the tympanic opening of auditory tube;

6) the *mastoid wall*, **paries mastoideus** is the posterior wall related to the mastoid process of temporal bone. The opening on the wall — the aditus to mastoid antrum leads to the greatest air cell called the *mastoid antrum*, **antrum mastoideum** and further to smaller mastoid air cells[1].

[1] inflammation of the middle ear may result in pus expansion to the mastoid air cells

The *auditory ossicles*, **ossicula auditus**

The tympanic cavity houses three auditory ossicles (Fig. 64):

- the *malleus* (Lat. Id.) consists of the head, the neck, the handle and two processes (the lateral and the anterior); the handle attaches to the tympanic membrane and the head articulates with the incus;
- the *incus* (Lat. Id.) features the body and two limbs (long and short);
- the *stapes* (Lat. Id.) features the head, the limbs and the *base of stapes*, **basis stapedis**. The head articulates with the incus and the base closes the oval window. The base of stapes attaches to the margin of the oval window by means of the *annular ligament of stapes*, **ligamentum annulare stapediale** (syndesmosis)[1].

The malleus attaches to the tympanic membrane with the handle and the stapes forms movable articulation with the oval window.

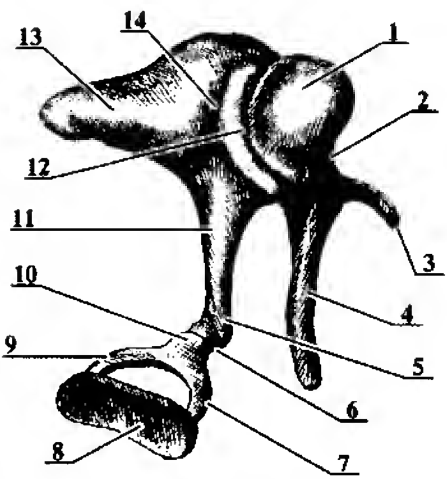


Fig. 64. The auditory ossicles. 1 — caput mallei; 2 — collum mallei; 3 — processus anterior mallei; 4 — manubrium mallei; 5 — processus lenticularis incudis; 6 — articulatio incudostapedialis; 7 — crus anterior stapedis; 8 — basis stapedis; 9 — crus posterior stapedis; 10 — caput stapedis; 11 — crus longum stapedis; 12 — articulatio incudomallearis; 13 — crus breve stapedis; 14 — corpus incudis.

The joints and ligaments of the auditory ossicles

The auditory ossicles form two joints:

- the *incudomallear joint*, **articulatio incudomalleolaris** formed of the head of malleus and the body of incus;
- the *incudostapedial joint*, **articulatio incudostapedialis** formed of the incus and the head of stapes;

The featured ligaments are like the following:

- the *anterior ligament of malleus*, **ligamentum mallei anterius**;
- the *lateral ligament of malleus*, **ligamentum mallei laterale**;
- the *superior ligament of malleus*, **ligamentum mallei superius**;
- the *superior ligament of incus*, **ligamentum incudis superius**;
- the *posterior ligament of incus*, **ligamentum incudis posterius**;

[1] with aging the annular ligament undergoes ossification, which results in hearing acuity loss (otosclerosis)

- the *stapedial membrane*, **membrana stapedialis;**
- the *annular ligament of stapes*, **ligamentum annulare stapediale**;

The muscles of auditory ossicles, **musculi ossiculorum auditus**

The auditory ossicles also feature two small muscles:

- the *tensor tympani*, **musculus tensor tympani** arises within the canal of the same name and attaches to the handle of malleus. Nerve supply is provided by the *trigeminal nerve*. Action — the muscle regulates tension of the tympanic membrane;
- the *stapedius*, **musculus stapedius** arises from within the *pyramidal eminence*, **eminentia pyramidalis** situated on the posterior wall of tympanic cavity. It attaches to the head of stapes. Nerve supply is provided by the *facial nerve*. Action — the muscle regulates oscillations of the stapes.

The *auditory tube*, **tuba auditiva**

The auditory tube communicates the tympanic cavity with the nasopharynx. The tube runs inferiorly and medially; it is 3.5 cm long and 2 mm wide.

The parts of the tube

The tube features the bony and the cartilaginous parts:

- the *bony part*, **pars ossea** occupies the canal of the same name (it is a portion of the musculotubal canal). This part constitutes the lateral 1/3 of the tube;
- the *cartilaginous part*, **pars cartilaginea** constitutes medial 2/3 of the tube.

The tube has two openings called the tympanic opening and the pharyngeal opening. The surface of tube is invested with the mucosa with featured tubal glands and lymphatic follicles.

THE INTERNAL EAR, AURIS INTERNA

The internal ear comprises the bony and the membranous labyrinths embedded into the pyramid of temporal bone.

The *bony labyrinth*, **labyrinthus osseus**

The bony labyrinth is a complex system of cavities and canaliculi made up of dense bone tissue (Fig. 65). The bony labyrinth houses the membranous labyrinth; the space between the two labyrinths is called the perilymphatic space, it contains a specific fluid called the perilymph. The bony labyrinth consists of the vestibule, the semicircular canals and the cochlea.

The *vestibule*, **vestibulum** is a dilated central portion of the labyrinth continuous with the cochlea anteriorly and with the semicircular canals posteriorly. On the wall of vestibule on can distinguish the *vestibular crest*, **crista vestibule** that delimits two recesses — the elliptical and the spherical:

- the *elliptic (utricular) recess*, **recessus ellipticus (utricularis)** resides superopsoteriorly. The recess contains the *internal opening of vestibular canaliculus*, **apertura interna canaliculi vestibuli**;

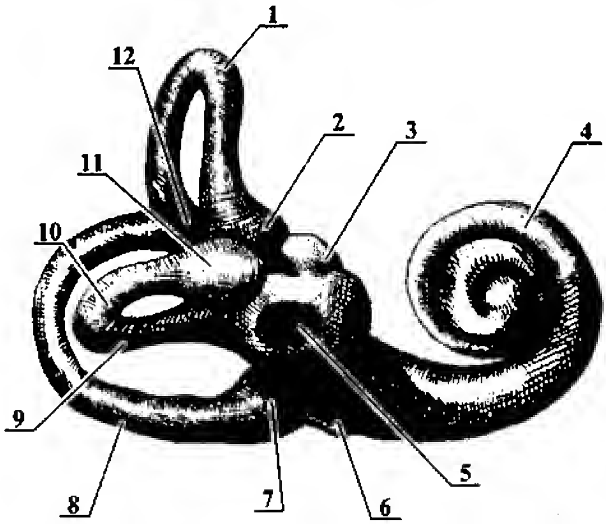


Fig. 65. External features of bone labyrinth. 1 — canalis semicircularis anterior; 2 — ampula ossea anterior; 3 — vestibulum; 4 — cochlea; 5 — fenestra vestibuli; 6 — fenestra cochleae; 7 — ampulla ossea posterior; 8 — canalis semicircularis posterior; 9 — crus osseum simplex; 10 — canalis semicircularis lateralis; 11 — ampulla ossea lateralis; 12 — crus osseum commune.

- the *spherical (saccular) recess,* **recessus saccularis** situated inferoanteriorly;
- the *cochlear recess,* **recessus cochlearis** is directly continuous with the spiral canal of cochlea.

The *semicircular canals,* **canales semicirculares** constitute the posterolateral portion of the labyrinth. The canals are related to three reciprocally perpendicular planes. The canals are as follows:

- the *anterior semicircular canal,* **canalis semicircularis anterior** is related to the longitudinal axis of the pyramid (to the sagittal plane);
- the *posterior semicircular canal,* **canalis semicircularis posterior** is parallel to the posterior surface of the pyramid (to the frontal plane);
- the *lateral semicircular canal,* **canalis semicircularis lateralis** lies in horizontal plane.

The simple and ampullary bony limbs

Each canal features two *bony limbs,* **crura ossea** that open into the vestibule. One limb of each canal features a dilation called the *bony ampulla,* **ampulla ossea**. Such limb is called the *ampullary bony limb,* **crus osseum ampullare**. The opposite limbs are not dilated and thus are called the *simple bony limbs,* **crura ossea simplex**. The simple bony limbs of the anterior and the posterior canals merge into one *common bony limb,* **crus osseum commune**. The vestibule thus features five openings of the canals.

The *cochlea* (Lat. Id.) is the anterior portion of the bony labyrinth.

The cochlea resides anteriorly to the vestibule and appears as a spiral bony tube that winds around the modiolus (Fig. 66).

In the beginning of its way, the cochlea gives rise to the *cochlear canaliculus*, **canaliculus cochleae** that opens at the cranial base. The cochlea features the parts like the following:

1) the *base*, **basis**, it faces the internal acoustic opening;

2) the *cochlear cupula*, **cupula cochleae** faces the tympanic cavity;

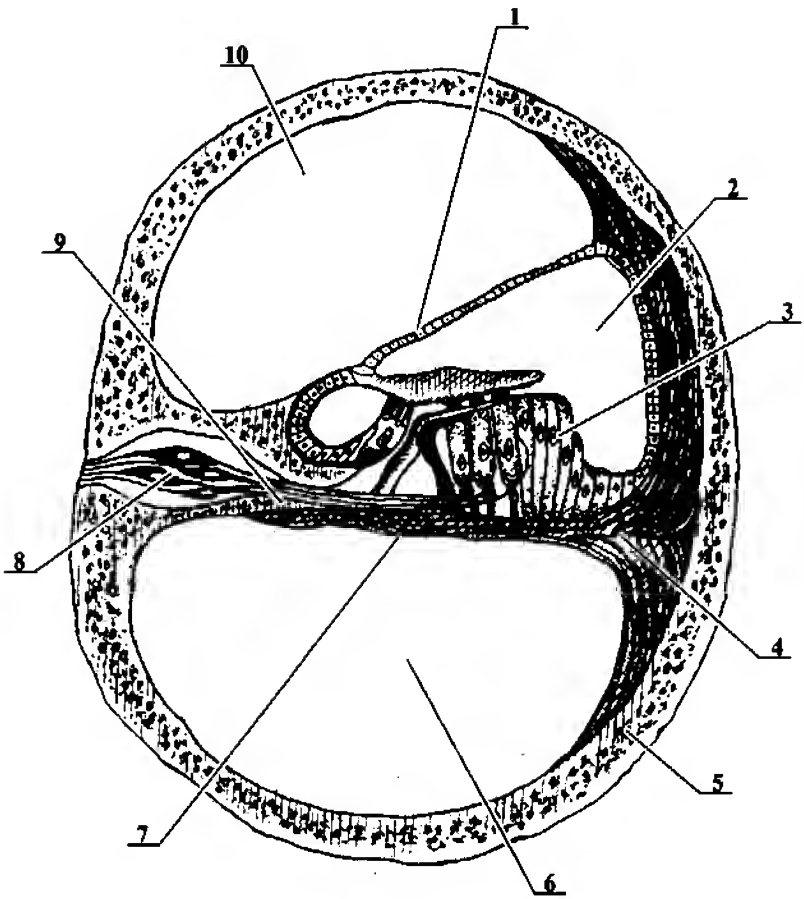


Fig. 66. Cross section of the cochlear canal. 1 — paries vestibularis ductus cochlearis; 2 — ductus cochlearis; 3 — organum spirale; 4 — lig. spirale; 5 — substantia ossea spongiosa; 6 — scala tympani; 7 — lamina basillaris; 8 — ganglion spirale; 9 — lamina spiralis ossea; 10 — scala vestibuli.

3) the *modiolus*, **modiolus cochleae** (the axis); the cochlea makes 2.5 twists around the modiolus. The modiolus has the parts as follows:

- the *osseous spiral lamina*, **lamina spiralis ossea**, it runs within the spiral canal of cochlea and separates it into two portions;
- the *spiral canal of modiolus*, **canalis spiralis modioli** runs within the base of osseous spiral lamina;
- the *longitudinal canals of modiolus*, **canales longitudinales modioli** arise from the spiral canal and open on the floor of the *internal acoustic opening*;
- the *helicotrema* (Lat. Id.) the opening that communicates the portions of spiral canal separated by the spiral lamina;

The *membranous labyrinth*, labyrinthus membranaceus

The membranous labyrinth resides within the bony labyrinth. Its walls are formed of connective tissue. The cavities of the membranous labyrinth are filled with clear fluid called the *endolymph*, **endolympha**. All these cavities form one *endolymphatic space*, **spatium endolymphaticum**.

The space between the bony and the membranous labyrinths is the *perilymphatic space*, **spatium perilymphaticum** filled with the *perilymph*, **perilympha**. The perilymph flows to the subarachnoid space via the *cochlear aqueduct*, **aqueductus cochleae** (it runs within the *cochlear canaliculus*) (Fig. 67).

The membranous labyrinth consists of the vestibular labyrinth and the cochlear labyrinth.

The *vestibular labyrinth*, **labyrinthus vestibularis** comprises the utricle, the saccule and three semicircular ducts:

- the *utricle*, **utriculus** occupies the elliptic recess of the vestibule. The utricle communicates with the semicircular ducts. On the internal surface of the utricular wall one can distinguish the *macula of utricle*, **macula utriculi** (a receptor area);
- the *saccule*, **sacculus** occupies the spherical recess of the vestibule. It communicates with the *cochlear duct* via the *ductus reuniens* (Lat. Id.). The internal surface of the saccule features *macula of saccule*, **macula sacculi** (also a receptor area);
- the *utriculosaccular duct*, **ductus utriculosaccularis** communicates the utricle with the saccule;
- the *endolymphatic duct*, **ductus endolymphaticus** arises from the utriculosaccular duct and terminates with the cul-de-sac incorporated into the dura mater of the posterior surface of pyramid; it serves for temporary storage of the endolymph drained (the endolymph never leaves the membranous labyrinth).

The *semicircular ducts*, **ductus semicirculares** fit the respective semicircular canals. The limbs related to the bony ampullae feature the *membranous ampullae*, **ampullae membra-**

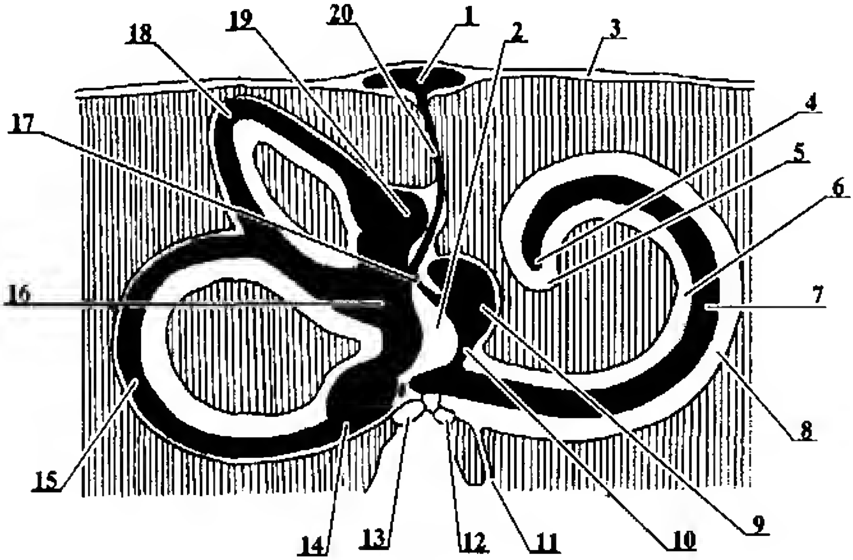


Fig. 67. Bone and membranous labyrinths. 1 — saccus endolymphaticus; 2 — spatium perilymphaticum; 3 — dura mater; 4 — cupula cochleae; 5 — helicotrema; 6 — scala vestibuli; 7 — ductus cochlearis; 8 — scala tymppani; 9 — sacculus; 10 — ductus reuniens; 11 — ductus perilymphaticus; 12 — fenestra cochleae; 13 — fenestra vestibuli; 14 — ampula membranacea posterior; 15 — ductus semicircularis posterior; 16 — utriculus; 17 — ductus utriculosaccularis; 18 — canalis semicircularis anterior; 19 — ampula membranacea anterior; 20 — ductus endolymphaticus.

naceae with *ampullary crests*, **cristae ampulares** featured. The simple limbs merge into a common membranous limb in the same fashion as the limbs of the semicircular canals do; the utricle thus features five openings of the ducts.

The receptor areas

The receptor areas of the vestibular labyrinth are represented with the following structures:

- the *macula of utricle*, **macula utriculi**;
- *macula of saccule*, **macula saccule**.

Both maculae consist of the sensory hair cells covered with jelly-like substance. The substance contains the crystals of calcium carbonate called the *otoliths*, **stratoconii**.

- the *ampullary crests*, **cristae ampullares** reside within each membranous amplla. They also comprise the sensory hair cells covered with the same jelly-like substance called the *ampullary cupula*, **cupula ampullaris**.

The neural pathways of the vestibular analyzer

The **first neurons** of the chain are the bipolar neurons of the *vestibular ganglion*, **ganglion vestibulare**

(it resides within the internal acoustic opening). The peripheral processes of these neurons proceed to the maculae and the ampullary crests via the respective foramina of the bony labyrinth. There they synapse with the receptor cells.

The central processes of the first neurons form the *vestibular part* of the vestibulocochlear nerve (the VIII cranial nerve), which arises from the internal acoustic opening on the posterior surface of pyramid. These fibers enter the pons and terminate in four vestibular nuclei[1] related to the vestibular area of the rhomboid fossa.

The **second neurons** form the vestibular nuclei; their axons reach the *fastigial nucleus,* the cerebellar cortex (these fibers run within the inferior cerebellar peduncles), the reticular formation of the brainstem, the nuclei of the III, the IV and the VI cranial nerves, the colliculi of the tectal plate and the spinal cord (the *vestibulospinal tract*). From the cerebellum, the impulses reach the red nucleus of the midbrain; the impulses from the vestibular apparatus thus reach the extrapyramidal system.

Functioning of the vestibular apparatus

Stimuli come to the receptors with simple and accelerated movements of the head. Moving endolymph dislodges the ampullary cupulae and the otoliths, which in turn results in excitation of receptors. The impulses generated run to automated processing units of CNS, which send the impulses to the motor nuclei. The motor nuclei send the impulses to the respective muscles.

The *cochlear labyrinth*, labyrinthus cochlearis

The cochlear labyrinth is represented with the *cochlear duct*, **ductus cochlearis**. The duct arises from the vestibule and runs spirally upwards to reach the cupule of cochlea.

The walls of the cochlear duct:

- the *tympanic surface (spiral membrane)*, **paries tympanicus (membrana tympanica)** expands between the osseous spiral lamina and the wall of spiral canal. It consists of numerous (about 24000) resilient connective tissue fibers of different length. The fibers form the basal lamina that supports the spiral organ;
- the *vestibular surface (membrane)*, **paries (membrana) vestibularis**[2] is a very thin connective tissue plate invested with squamous epithelium on both sides; the membrane also expands between the spiral lamina and the wall of spiral canal yet it slants to the basal lamina at 45°;
- the *external surface*, **paries externus** is formed of connective tissue

[1] some fibers reach the cerebellum directly
[2] the Reissner's membrane

attached to the bony wall of the spiral canal.

The perilymphatic spaces

The cochlear duct is much smaller than the entire spiral canal so here one can see wide perilymphatic spaces (scalae):

- the *scala vestibuli* (Lat. Id.) is a space formed of the vestibular surface and the bony wall of spiral canal;
- the *scala tympani* (Lat. Id.) the space formed of both spiral laminae and the bony wall of spiral canal.

The scalae maintain communication via the *helicotrema* (Lat. Id.).

The **auditory receptors** appear as the *spiral organ (the organ of Corti)*, **organum spirale (organum Corti)** situated on the basal membrane. The spiral organ consists of epithelial cells; some are the sensory hair cells. The spiral organ is covered with the *tectorial membrane*, **membrana tectoria** responsible for stimulation of sensory cells.

The pathways of auditory analyzer

The **first neurons** of the chain form the spiral ganglion found within the spiral canal of modiolus (Fig. 68).

The peripheral processes of these cells synapse with the sensory cell of spiral organ while the central processes quit the longitudinal canals of modiolus and merge to form the *cochlear part* of the vestibulocochlear nerve (the VIII cranial nerve).

The fibers of the cochlear part quit the internal acoustic meatus and enter the pons to terminate in the anterior and posterior cochlear nuclei.

The **second neurons** form the cochlear nuclei. Their axons decussate (they form the trapezoid body) and proceed to the opposite side[1]. The axons of the posterior cochlear nuclei appear as the *medullary stria of fourth ventricle* that cross the rhomboid fossa. They meet midline and enter the pons to join the trapezoid body. The decussated fibers form the lateral lemniscus that ascends to the inferior colliculi of tectal plate and the medial geniculate bodies of metathalamus.

The **third neurons** reside within the inferior colliculi of tectal plate and the medial geniculate bodies.

The axons of the cells of inferior colliculi form the *tectospinal tract* and the axons given by the geniculate bodies traverse the posterior limb of internal capsule and fan out to form the *acoustic radiation*, **radiatio acustica**. These fibers terminate within the auditory cortex of superior temporal gyrus (the transverse temporal gyri or the Heshl's gyri).

Origination of auditory sensation

The sound waves directed by the external acoustic opening set the tympanic membrane in motion. Membrane oscillations reach the base of stapes via the system of auditory ossicles. The stapes forms a movable articulation with the oval

[1] some fibers run on the same side

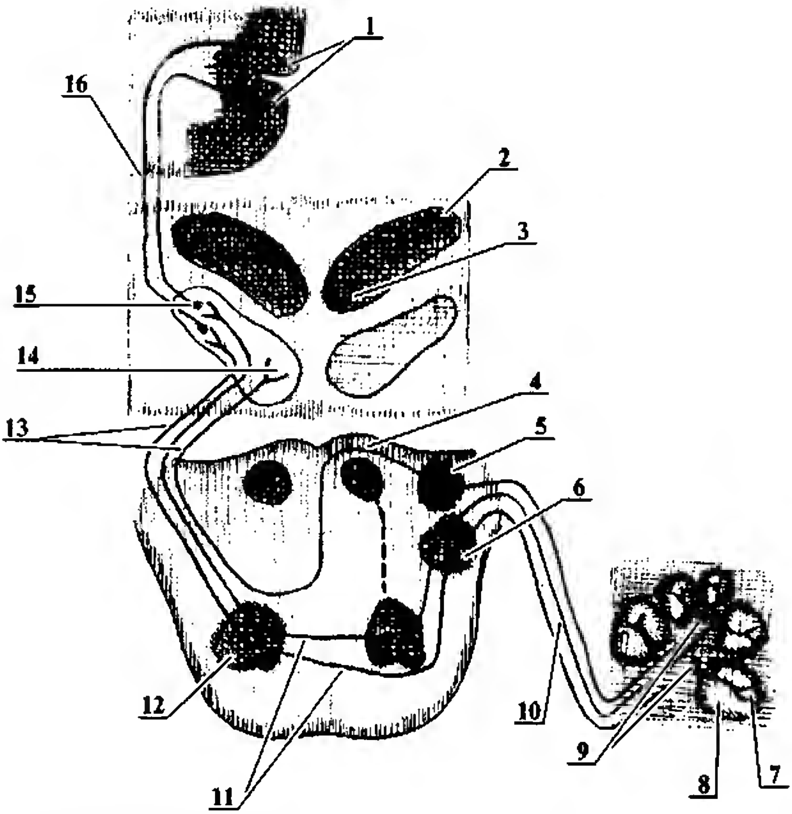


Fig. 68. The auditory pathways. 1 – gyri temporales transversi; 2 – corpus geniculatum lateralis. 3 – colliculus superior; 4 – striae medullares ventriculi quarti; 5 – nucl. cochlearis dorsalis; 6 – nucl. cochlearis ventralis; 7 – ductus cochlearis; 8 – scala tympani; 9 – ganglion spirale; 10 – pars cochlearis n. vestibulocochlearis; 11 – corpus trapezoideum; 12 – nucl. olivaris superior; 13 – lemniscus lateralis; 14 – colliculus superior; 15 – corpus geniculatum medialis; 16 – radiatio acustica.

window and waves thus proceed to the perilymph of the scala vestibuli and further to the scala tympani via the helicotrema. There they meet the secondary tympanic membrane and fade out.

Perilymphatic waves generate secondary endolymphatic waves, which results in displacement of basal membrane and the tectorial membrane. Oscillations of the membranes stimulate the receptor cells that generate nerve impulses. The fibers of the basal membrane are responsible for frequency distinguishing because of different length (longer at the base and shorter at the apex). The nerve impulses reach the temporal lobe via the vestibulocochlear nerve and related neural pathways.

EVOLUTION OF VESTIBULAR AND AUDITORY ORGANS

The auditory and vestibular organs in invertebrates

The water animals first develop the equilibrium organs represented with ectodermic fossae or vesicles filled with fluid. The vesicles are invested with sensory hair cells and contain freely movable "stones" or statoliths. Movements of the body cause displacement of the statoliths that stimulate the receptor cells. Many invertebrates (jellyfish, shellfishes etc) feature such primitive equilibrium organs. The terraneous invertebrates (e.g. insects) also feature auditory organs formed of resilient septa that accept the sound waves (tympanal organs).

The auditory and vestibular organs in vertebrates

In vertebrates, both organs join into one complex vestibulocochlear organ. The water animals (e.g. Cyclostoma or fish) yet feature only equilibrium organ represented with semicircular canals filled with fluid and small statoliths. In fish, the canals lie in three reciprocally perpendicular planes with respect to three spatial dimensions.

The terraneous animals (amphibians) develop middle ear from the first branchial fissure. It appears as an air-filled cavity sealed with the tympanic membrane. The external ear transmits the sound waves to the internal ear. The latter also features underdeveloped cochlea. Only birds and crocodiles have well distinguishable cochlear duct, which appears as curved tube. The mammals feature fully developed cochlea. They also have well developed external ear with featured auricle and external acoustic meatus.

Development of the vestibulocochlear organ in humans

Origination of otocyst

The internal ear primordia arise from the otic placode – the lateral thickened portion of the posterior cerebral vesicle. The placode soon transforms into the otic fovea. Further, the fovea grows deeper and closes to form the otocyst filled with fluid.

Origination of the labyrinth

The otocyst first gives rise to the saccule, the utricle and the semicircular ducts. Later on, the anterior portion of the otocyst gives rise to the cochlear duct.

The neuroblasts situated along the walls of the otocyst differentiate into the receptor sets of the spiral organ, the maculae and the ampullary crests. The peripheral processes of the common ganglion of vestibulocochlear nerve reach the sensory cells to synapse with them. The common ganglion splits into the spiral and the vestibular ganglia.

The mesenchymal cells group around the growing membranous labyrinth and eventually form the cartilaginous labyrinth that later undergoes ossification.

Origination of the middle and the external ear

The tympanic cavity originates from the first branchial cleft. The cleft also gives rise to the pharyngotympanic tube. The first and the second visceral arches give rise to the auditory ossicles. In the beginning of development, the tympanic cavity is almost filled with the embryonic connective tissue, which gradually disappears with embryo growth.

The auricle originates from the submandibular and the hyoid visceral arches. The fissure in between the arches gives rise to the external acoustic opening.

THE OLFACTORY ORGAN, ORGANUM OLFACTORIUM (OLFACTUS)

The **receptors of the olfactory organ** occupy the olfactory part of nasal mucosa – the area related to the superior nasal concha and adherent portion of the nasal septum (its area is about 2-3 cubic cm).

The olfactory part comprises three types of cells – the receptor cells, the supporting cells and the basal cells. The supporting cells separate the receptor cells. They feature short ciliary processes and possess secretory function. The basal cells reside deeper; they separate the axons of receptor cells. Below the basal membrane, one can distinguish the glandular goblet cells.

The receptors are the modified bipolar neurons that are the first neurons of the olfactory pathway (Fig. 69). Their peripheral processes pass through the cribriform plate of the ethmoid as the *olfactory nerves*, **nervi olfactorii** (20-25 nerves). These fibers constitute the I pair of cranial nerves. They reach the olfactory bulb to synapse with the pertaining cells. The dendrite of each receptor cell ends with the dilation (the olfactory club) with 10 to 12 olfactory hair on it.

The **second neurons** of the chain reside within the olfactory bulb (the mitral cells); their axons extend posteriorly as the *olfactory tract*, which terminates within the *olfactory trigone*, the *anterior perforated substance* and the *septum pellucidum*. These areas contain the **third neurons** of the pathway.

Some fibers given by the neurons of the olfactory bulb run directly to the amygdaloid body and the olfactory cortex of the parahippocampal gyrus (the lateral olfactory stria).

The axons of the third neurons loop around the corpus callosum both above and below; some fibers cut the way to the temporal lobe (they run within the olfactory stria). All fibers terminate within the un-

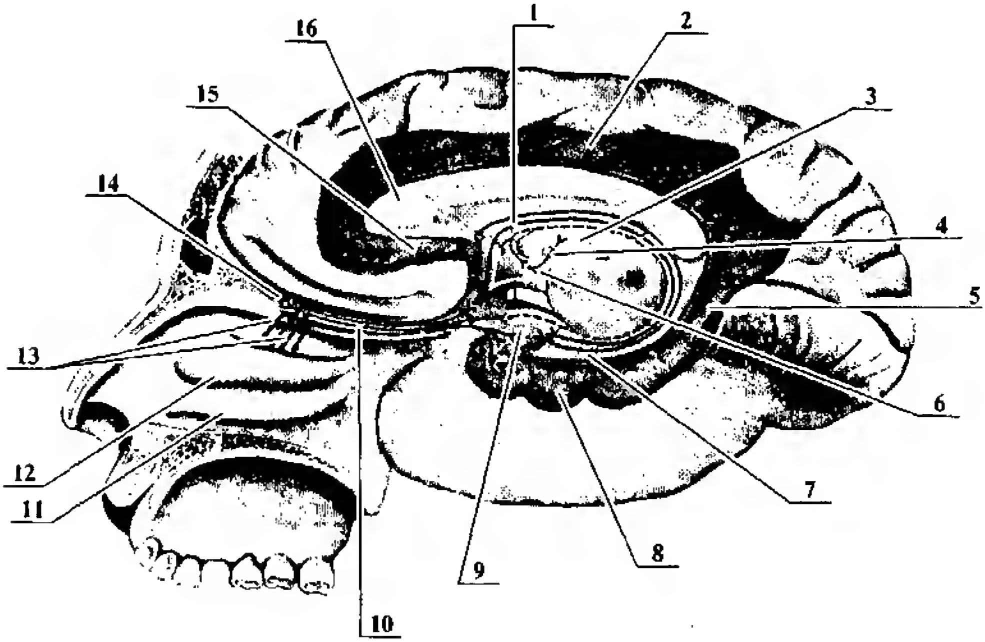


Fig. 69. The olfactory pathways. 1 — fornix; 2 — gyrus cinguli; 3 — thalamus; 4 — tr. mamillothalamicus; 5 — isthmus gyri cinguli; 6 — corpus mamillare; 7 — gyrus dentatus; 8 — gyrus parahippocampalis; 9 — uncus; 10 — tractus olfactorius; 11 — concha nasalis inferior; 12 — concha nasalis midia; 13 — fila olfactoria; 14 — bulbus olfactorius; 15 — area subcallosa; 16 — genu corporis callosi.

cus of the parahippocampal gyrus. The olfactory centers feature associations with the mammillary bodies, which in turn are associated with the thalamus (via the mamillothalamic fasciculus of the fornix); the reticular formation and the nuclei of the cranial nerves also feature associations with these centers. Between the septal cartilage and the vomer one can distinguish the *vomeronasal organ*[1], **organum vomeronasale** which is the peripheral part of the accessory nervous system

The olfactory analyzer is one of the oldest ones so it features several fibers that take the shortest route to the olfactory cortex i.e. do not relay within the thalamus. Emotions associated with the smells are typical for the system because of vast associations with the limbic system.

[1] the Jacobson's organ

THE GUSTATORY ORGAN, ORGANUM GUSTATORIUM (GUSTUS)

The *taste bud*, **caliculus gustatorius (gemma gustatoria)**

The receptors of the gustatory analyzer are represented with the *taste buds*, **caliculi gustatorii** situated within all papillae of tongue except for the filiform papillae. Single taste buds occur in the buccal mucosa, the palatine mucosa, the epiglottic mucosa and the posterior wall of the pharynx. The taste buds comprise the epithelial cells; some of them are the receptor hair cells. The taste buds are in contact with the gustatory fibers of the facial, the lingual and the glossopharyngeal nerves.

The **first neurons of the pathway** are the pseudounipolar neurons of the sensory ganglia of facial and glossopharyngeal nerves:

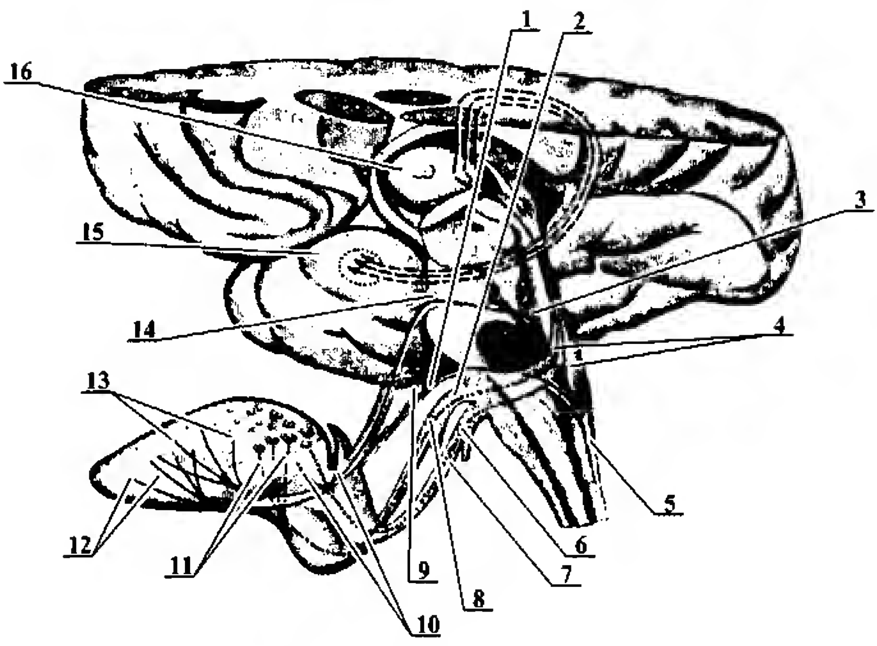


Fig. 70. The gustatory pathways. 1 — n. facialis; 2 — n. glossopharyngeus; 3 — nucl. pontinus n. trigemini; 4 — nucl. solitarius; 5 — medulla oblongata; 6 — n. vagus; 7 — gangl. inferius n. vagi; 8 — gangl. inferius n. glossopharyngei; 9 — gangl. geniculi; 10 — смакові волокна n. vagi; 11 — смакові волокна n. glossophryngei; 12 — смакові волокна chordae tympani (n. facialis); 13 — волокна загальної чутливості (n. lingualis); 14 — gangl. trigeminale; 15 — uncus; 16 — thalamus.

1) the *geniculate ganglion*, **ganglion geniculi** sends the peripheral processes to the facial nerve, to the chorda tympani and to the lingual nerve that supply the anterior two thirds of tongue. The central processes join the intermediate nerve and terminate within the nucleus of solitary tract (of the medulla oblongata);

2) the *inferior ganglion*, **ganglion inferius** of the glossopharyngeal nerve (the IX pair) gives the fibers to the glossopharyngeal nerve; they supply the posterior third of the tongue. The central processes also reach the nucleus of solitary tract.

The **second neurons** of the pathway are the neurons of the nucleus of solitary tract; their axons decussate and join the medial lemniscus that ascends to the thalamus.

The axons of the thalamic neurons traverse the posterior limb of the internal capsule and reach the superior analyzing units of the *uncus* of the *parahippocampal gyrus*.

THE INTEGUMENT, INTEGUMENTUM COMMUNE

The *skin*, **cutis** houses numerous nerve terminals that receive numerous environmental stimuli.

The layers of skin

The skin features three layers as follows:

- the *epidermis* (Lat. Id.) is the outer layer formed of stratified epithelium. The epidermis features deep basal (germinative) and superficial keratinized layers; the epidermis is of ectodermic origin;
- the *dermis* or *corium* (Lat. Id.) comprises fibrous and elastic connective tissue fibers of mesodermic origin. The dermis features the *papillary layer*, **stratum papillare** with numerous *papillae* (Lat. Id.) that get deep into the epidermis to leave the *skin sulci*, **sulci cutis** and the *papillary ridges*, **cristae cutis**;
- the *subcutaneous tissue*, **tela subcutanea** is formed of fatty tissue.

The skin analyzer

The skin contains numerous nerve terminals (receptors) that accept pain, temperature and tactile stimuli. The impulses generated proceed via the sensory nerves and related pathways (see the exteroceptive pathways) to the cerebral cortex. The postcentral gyrus, the pathways, the nerves and the receptors constitute the skin analyzer.

The glands and corneous derivatives

The skin contains the *sweat glands*, **glandulae sudoriferi** and the *sebaceous glands*, **glandulae sebaceae** (they reside within the dermis) and corneous derivatives – the nails and the hairs:

- the *nail*, **unguis** features the *nail matrix*, **matrix unguis**, the *body of nail*, **corpus unguis**, the *root of nail*, **radix unguis** and the *free border*, **margo liber**;
- the *hairs*, **pili** feature the *arrector muscles of hair*, **musculi arrector pili** that raise the hair.

The breast (mammary gland), mamma

Synonym '**mastos**' gives rise to 'mastitis' — inflammation of breast.

The breasts are the highly modified sweat glands of ectodermic origin. In females they are of rounded shape; the breast adheres to the pectoral fascia at the level of ribs 3 through 6.

Structure of breast

The breasts are the compound alveolar-tubular glands with features as follows:

- the *nipple*, **papilla mammaria** is the central portion of the areola; it features 10 to 15 openings of the excretory ducts;
- the *areola*, **areola mammae** is the pigmented area of the breast; it features the *areolar glands*, **glandulae areolares**;
- the *lobes of mammary gland*, **lobi glandulae mammariae** (15 to 20 at all) are the portions separated with the connective tissue septa. The lobes actually constitute the *mammary gland*, **glandula mammaria**;
- the *lactiferous ducts*, **ductus lactiferi** run to open on the surface of nipple. Before opening, the ducts become continuous with dilated *lactiferous sinuses*, **sinus lactiferi**.

The male breasts (the term *masculine breast*, **mamma masculina** has been removed from current anatomical terminology) actually contain the same yet underdeveloped structures.

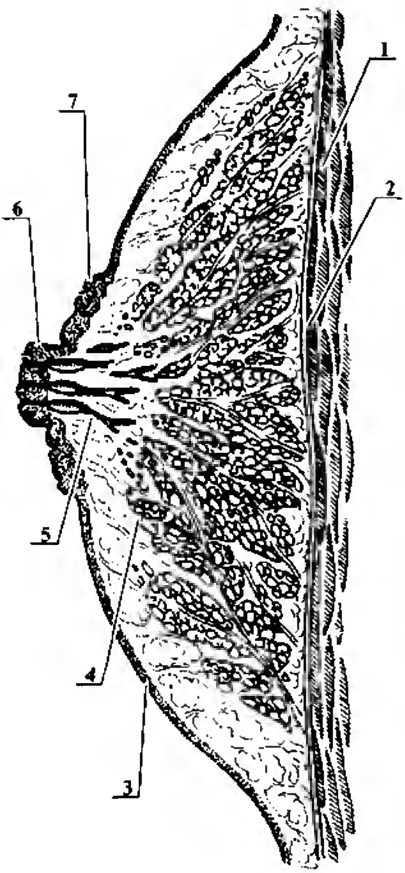


Fig. 71. The breast, sagittal section. 1 — m. pectoralis major; 2 — fascia pectoralis; 3 — cutis; 4 — lobi glandulae mammariae; 5 — ductus lactiferi; 6 — papilla mammaria; 7 — areola mammae.

Practice questions

1. Name three compartments of analyzer.
2. Name types of receptors featured by sense organs.
3. Describe main stages of evolution of sense organs.
4. Describe the parts and topography of the eye.
5. Describe development, developmental anomalies and external features of eyeball.
6. Name and recognize the layers of eyeball.
7. Describe the fibrous layer of eyeball
8. Describe the vascular layer if eyeball.
9. Describe the retina.
10. Describe the refractive media of eyeball
11. Describe the chambers of eyeball.
12. Describe production and circulation of the aqueous humor.
13. Name the accessory visual structures.
14. Describe the conjunctiva.
15. Describe the extrinsic muscles of eyeball.
16. Describe lacrimal apparatus and circulation of lacrimal fluid.
17. Describe formation and topography of the optic nerve.
18. Describe the visual pathway.
19. Name and recognize the principal pars of ear. Discuss embryonic development of the ear and its developmental anomalies.
20. Describe the external ear.
21. Describe the auricle.
22. Describe the external acoustic meatus.
23. Describe the tympanic membrane.
24. Describe the middle ear.
25. Describe the tympanic cavity with related canals.
26. Describe the auditory ossicles with related joints and muscles.
27. Describe the auditory tube.
28. Name the parts of internal ear.
29. Describe the bony labyrinth.
30. Describe the semicircular canals.
31. Describe the vestibule.
32. Describe the cochlea.
33. Describe membranous labyrinth.
34. Describe the perilymphatic space.
35. Describe the endolymphatic space.
36. Describe the vestibular part of membranous labyrinth.
37. Describe the semicircular ducts.
38. Describe the cochlear duct.
39. Describe the route of sound waves.
40. Describe the auditory pathway.
41. Describe the vestibular pathway.
42. Describe the olfactory organ.
43. Describe the gustatory organ.
44. Name the parts of integument.
45. Describe the breast.

THE CARDIOVASCULAR SYSTEM, SYSTEMA CARDIOVSACULARE

Terminology

The word 'angiology' originates from Greek '**angion**' – the vessel and '**logos**' – study. The Latin term '**vas**' – the vessel, is in use for both blood and lymphatic vessels. It gives rise to numerous medical terms like vasodilation, vasography etc. The term '**vascularization**' – blood supply originates from the diminutive '**vasculum**' (Latin) – a small vessel.

The cardiovascular system is divided into the blood circulatory system and the lymphatic system. The systems keep tight structural and functional associations. Both systems and the heart constitute one cardiovascular system. The system serves for blood and lymph circulation and thus provides the organs and tissues with nutrients, hormones, vitamins and oxygen and serves for withdrawal of waste products. Apart from this, both blood and lymph contain the lymphocytes and antibodies responsible for protective function (immunity) of blood.

THE CIRCULATORY SYSTEM

Arrangement of circulatory system

The central organ of the circulatory system is the heart with pertaining blood vessels. The blood vessels are the arteries, the capillaries and the veins. The vessels that withdraw the blood from heart are the arteries (from Greek '**aer**' – air and '**tereo**' – to contain; in ancient times they were believed to carry the air). The arteries diverge and become continuous with the capillary network, which in turn re-merges to form the veins. The veins carry the blood back to the heart.

The systemic and pulmonary circulation routes

The *systemic circulation* arises from the left ventricle with the aorta, which carries the arterial (oxygenated) blood. The arteries given by the aorta carry the blood all around the body. The arterial network becomes continuous with the capillary network where the blood gives oxygen and nutrients to the respective tissues. The capillaries become continuous with the veins that carry deoxygenated (venous) blood back to the heart. The greatest veins of the systemic circula-

tion are the superior and the inferior venae cavae. They enter the right atrium, where the systemic circulation route ends (Fig. 72).

The *pulmonary circulation* arises from the right atrium with the pulmonary trunk. The trunk splits into the left and the right pulmonary arteries that carry the venous blood to the pulmonary capillaries where oxygenation occurs. Oxygenated blood is carried by the pulmonary veins that open into the left atrium. Thus, in the pulmonary circulation route, the veins carry the arterial blood and vice versa.

Differences between the arteries and the veins lie in wall structure and blood flow direction. The arteries are the vessels that carry the blood away from the heart; the blood is forced through the arteries under relatively high pressure so the arteries feature rather thick walls with well-developed elastic and muscular layers. The veins carry the blood to the heart; the blood pressure there is lower than that in arteries so the venous walls feature scarce muscular and connective tissue layers.

Two circulation routes (the blood takes one route yet enters the heart twice) are distinguished for the reasons of different gas exchange events within featured capillary networks. Within the systemic capillaries, the *arterial* blood undergoes deoxygenation and becomes the *venous* blood. The pulmonary capillaries perform oxygen saturation of *venous* blood, which becomes the *arterial* blood.

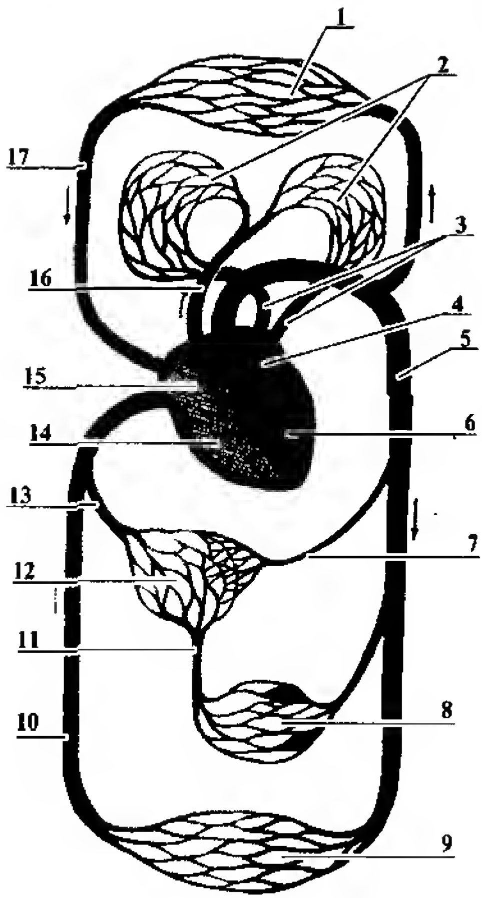


Fig. 72. The systemic and the pulmonary routes (scheme). 1 — капіляри голови, шиї, верхніх відділів тулубу та верхніх кінцівок; 2 — капіляри легень; 3 — vv. pulmonales; 4 — atrium sinistrum; 5 — aorta; 6 — ventriculus sinister; 7 — a. hepatica communis; 8 — капіляри кишечнику; 9 — капіляри нижніх відділів тулубу та нижніх кінцівок; 10 — v. cava inferior; 11 — v. portae hepatis; 12 — капіляри печінки; 13 — vv. hepaticae; 14 — ventriculus dexter; 15 — atrium dextrum; 16 — truncus pulmonalis; 17 — v. cava superior.

Distinguishing of 'the third circulation route' (the coronary vessels) is inconsistent with this principle and thus is unnecessary.

History of circulation studies

Correct concept of blood circulation was designed by great English anatomist and physiologist W. Harvey (1578-1657).

Before Harvey's studies, the medical science had been guided by C. Galen's misconception for at least 15 centuries. According to Galen's theory, the blood originates in the liver and proceeds to the right atrium and the right ventricle via the inferior vena cava. The blood traverses the pores in the interventricular septum and appears within the left ventricle where it is saturated with 'pneuma' taken from air. The blood enriched thus with the 'animal spirit' (spiritus animalis) flows forced by the pulsation power around the body and nourishes the organs.

In the 15th century, the Spanish doctor and theologian Michael Servetus gave a correct description of pulmonary route. It was published in "Christianity renovation" treatise (1550). Later, in 1559, A. Vesalius' student Realdo Colombo made independent discovery of the pulmonary circulation. These works anticipated further circulation studies.

W. Harvey was born in UK in 1578. He studied medicine first in Cambridge and then in famous university of Padua. Upon return from Padua, he worked at department of anatomy and surgery in London. After a long work, for which he used both anatomical and experimental research methods, he issued his renowned "*Exercitio Anatomica de Motu Cordis et Sanguinis in Animalibus*" (1628). In this work, Harvey gave detailed description of blood circulation in both routes. He was the first to prove that blood never exhausts and continuously circulates within blood vessels. Harvey knew but little about capillaries yet he admitted presence of invisible structures that link the arteries and the veins.

The capillaries were discovered by Italian scientist Marcello Malpighi (1628-1694). In 1661, after Harvey's death, he discovered capillaries in the lungs of living toad (the term 'capillary' was coined by Malpighi; it derives from Latin **'capilli'** – the hairs). Malpighi's works summed up the study of blood circulation.

THE ARTERIES, ARTERIAE

Structure of arterial wall (details are discussed in histology course)

The arterial wall features three layers – the adventitia, the middle and the inner tunics:

- the *tunica externa (adventitia)* (Lat. Id.) is the external tunic formed of connective tissue; the tunic houses the *vascular nerves*, **nervi vasorum** and the *vasa vasorum* (Lat. Id.);
- the *tunica media* (Lat. Id.) is the thickest tunic; it comprises the elastic and smooth muscular fibers;
- the *tunica intima* (Lat. Id) consists of elastic fibers and endothelium.

Depending on amount of elastic and muscular tissues, the arteries are divided into elastic, muscular and mixed types.

The arteries of elastic type contain well-developed connective tissue in the tunica media (the aorta, the pulmonary trunk, the carotid arteries, the subclavian arteries, the iliac arteries etc.). Because of abundant elastic tissue, these vessels are able to expand greatly and recoil with blood pressure alteration. These vessels easily resist blood pressure increment (namely systolic) and thus ensure uninterrupted blood flow.

The arteries of muscular type feature well-developed muscular layer. They are medium-sized and small arteries. Apart from blood passage, the muscular-type arteries provide regulation and redistribution of blood flow.

The mixed-type arteries constitute the transitional type of arteries. Generally, the muscular layer enlarges and elastic tissue layer reduces with vessel diameter decrease.

Anastomoses

The arteries feature more or less developed peripheral links called anastomoses (from Greek '**anabi**' and '**stoma**' – the mouth). Intersystem anastomoses link the branches of different main arteries and intrasystem ones link the branches pertaining to one main artery. The anastomoses are of great importance for blood flow redistribution and collateral circulation. Some areas feature vast anastomoses some have none. Knowledge on anastomoses location is important for many clinical specialties.

The network-type and the terminal-type arteries

The network-type arteries form vast anastomoses before splitting into capillary network. Withdrawal of any branch from the system will not affect blood supply of the related area greatly because blood reaches the capillaries via anastomotic vessels. Such arteries supply the stomach, the intestines, skin and some other organs.

The terminal-type arteries and related branches form no significant anastomoses. Here withdrawal of artery (thrombosis, embolism) affects the entire responsibility area of the artery; in absence of anastomoses blood fails to reach the capillary network, which results in necrosis of respective area (infarction).

Such arteries supply the liver, the spleen, the brain, the retina and the heart. Most of the organs listed feature minute anastomoses yet they are referred to as terminal-type vessels for functional and practical reasons.

Distributional regularities of arteries

In 1885, P.F. Lesgaft pooled all data on location and branching of the arteries and issued the following distributional regularities of these vessels:

1) the arteries take the shortest route to the responsibility area;

2) all main arterial trunks run along the concave sides of body and extremities;

3) the trunks split with respect to bony scaffold and rejoin on periphery with arched links;

4) size of each artery depends on the organ activity;

5) arteries form the networks and give collateral branches within movable areas.

In addition to the rules listed, one should add that the arteries of trunk retain segmental arrangement (like intercostal and lumbar arteries). The main trunks run within the neurovascular bundles enfolded into fascial sheaths (N.I. Pirogov). The neurovascular bundles occupy the protected areas (the grooves and canals formed of bones, muscles and fasciae). No large vessels run immediately below the skin. With the respect to the common division of the organism into the *soma* and the *viscera*, the vessels are the *parietal* and the *visceral*.

Angiogenesis law

The intrinsic arterial networks vary depending on organ. In the beginning of the 20th century, the German scientist W. Spatelholz (1861-1940) implemented a so-called angiogenesis law, which states that the organ primordia shape specifies its future blood supply.

In the solid organ primordia, the artery reaches its center to give off the peripheral branches. The organs supplied this way are the spleen, the kidneys, the muscles etc.

The tubular primordia in turn features superficial arterial network, which gives smaller radiating arteries into depth of the organ. The organs of this type are the spinal cord, the brain, the intestines, the heart etc.

The updated angiogenesis law nowadays is still of great importance for medicine.

Collateral circulation

In the case of main trunk withdrawal (thrombosis, ligaturing etc), the blood takes the side (collateral) branches to bypass the affected area. Sufficient number of collateral branches that anastomose with the distal main arteries may fully restore the blood supply of the area affected.

The problem of collateral circulation attracted interest of English anatomist E. Cawper, who was the first to ligature the common carotid artery. Later, N.I. Pirogov in his M.D. thesis dedicated to ligaturing of the abdominal aorta showed that gradual ligaturing of aorta allows dilation of the collateral vessels and partial restoration of blood supply.

Many modern aspects of collateral circulation were considered by Leningrad anatomy school (V.M. Tonkov, B.A. Dolgo-Saburov). The researchers performed numerous experiments with ligaturing and removal of various arteries. They showed that the circulatory system features vast capabilities, flexibility and good adaptation to collateral circulation. Under conditions of collateral circulation, the side arteries enlarge, their wall structure alters and they become twisted; the new vessels develop as well.

These data are of great importance for management and treatment of

atherosclerosis, embolism, infarction, obliterating endarteritis and other vascular diseases. Studying anatomy, one should keep in mind collaterals arise points and presence or absence of anastomoses for correct assessment of possible collateral circulation in the affected area.

MICROCIRCULATION

What does microcirculation stand for? Blood flow within the smallest blood vessels of the transi*tional segment is called microcircula*tion. Now, the transitional segment that links the arteries and the veins is called the microcirculatory network.

The novel data show that the microcirculatory network is a vital system that influences all physiological processes and is of great significance for pathology.

A great contribution to the microcirculation studies was made by Zweifach, Clark and Chambers (1934-1944). In former Soviet Union, V.V. Kupriyanov and A.M. Chernukh won the State Award in 1977 for investigations of microcirculation.

Morphological components of microcirculatory network

The microcirculatory network comprises the following components (Fig. 73):

- the *arterioles*, **arteriolae** (160-30 μm in diameter) arise from the arteries; they feature one or two layers of muscular cells;
- the *precapillary vessels*, **vasa precapillaria** (20 to 12 μm) arise from the arterioles. They possess features of both arterioles and capillaries. The precapillaries feature muscular fibers that form the precapillary sphincters. They however, consist mostly of endothelium and thus participate in exchange processes;
- the *capillaries*, **vasa capillaria** arise from the precapillaries. They consist only of endothelial cells adherent to basal membrane. The capillaries merge to form the capillary network. The capillaries are the principal *exchange vessels;*
- the *postcapillary vessels*, **vasa postcapillaria** arise from merging capillaries. They are similar to the precapillaries both structurally and functionally;

Fig. 73. The mesenteric microcirculatory network. 1 — vena; 2 — arteriola; 3 — rete capillare; 4 — vasa lymphatica et limphocapillare; 5 — venula; 6 — arteria.

- the *venules*, **venulae** arise from the postcapillaries. They are the paired vessels that accompany the arterioles. The venules larger than 50 μm feature the muscular fibers. The venules become continuous with the veins;
- the *arteriolovenular anastomoses*, **anastomoses arteriolovenularis** (the vascular shunts) link the arterioles and venules directly. They feature circular muscular fibers that regulate blood flow within the microcirculatory network.

The capillaries and A. Krogh's studies

In 1919, a Dutch scientist A. Krogh (1874-1949) gave first detailed description of capillaries and regarded it to be important segment of circulatory system. These studies brought him Nobel Prize in 1922. A. Krogh estimated length of capillaries (about 100 000 km) and their total area (about 6300 sq meters); he also performed comparative studies of capillary density (per 1 sq mm) in muscle tissue of various animal species. He found out that capillaries vary depending on organ and that the network density is specified by intensity of tissue metabolism.

From functional point of view, three states of capillaries are distinguishable:

1) active (fully open);
2) semi-active (plasmatic);
3) resting (fully closed).

Opening or closing of capillary lumens is under responsibility of precapillary sphincters. Increasing metabolism involves more capillaries closed in resting state.

The capillary wall is a semi-permeable membrane responsible for molecules transporting.

THE VEINS, VENAE

Synonym '**phleba**' gives rise to 'phlebitis' (vein inflammation), 'thrombophlebitis', 'phlebography' and other medical terms.

Wall structure

The wall of greater veins is similar to the arterial wall yet it is much thinner. The muscular and elastic elements in the venous wall are scarce because of low blood pressure. The veins are less resilient as well and are able to stretch considerably.

The venous valves

Unlike the arterial blood, the venous blood ascends against gravity (except for the veins of head and neck) and has no specific forcing power so they feature the valves that prevent blood backflow.

The *venous valves*, **valvulae venosae** are paired crescent-shaped recesses formed of intima folds. Free margins of the valves are directed to the heart to ensure one-way blood flow. Areas next to the valves are dilated (they are the venous sinuses).

The veins of upper and especially lower limbs have more valves than the veins of trunk and neck. The greater veins (both venae cavae), the veins of head, the renal veins, the hepatic portal vein and the pulmonary veins have no valves.

The blood is forced through the veins by massaging action of skeletal muscles, contractions of venous muscular tunic and aspirating force of the heart and the diaphragm.

Classification of veins

The somatic veins are divided into the superficial and the deep veins:

- *superficial veins*, **venae superficiales** run immediately below the skin; they do not accompany the arteries ;
- the *deep veins*, **venae profundae** run along the arteries. Each artery is accompanied by two veins of the same name (the venae comitantes). The deep veins anastomose with the superficial ones.

The venous plexuses (plexus venosus)

The plexuses arise from vast anastomoses between the veins. The most expressed plexuses are the plexuses of pelvic viscera and of the vertebral column.

The **venous sinuses (sinus venosus)** originate from the dura mater and thus consist of dense fibrous tissue. Such sinuses reside within the cranial cavity only.

Depot function of venous system

Greater capacity of venous system is due to larger diameters of veins as compared to the arteries. Venous capacity within the systemic route is twice as large as the arterial; the veins however feature significant wall elasticity, which allows considerable diameter enlargement and thus capacity increase. Venous capacity also results from presence of dense venous plexuses and low blood pressure. According to some data, the venous system houses up to 70% of the entire blood volume (Wood, 1965). Venous system thus serves for blood redistribution under several physiological and pathological conditions (shock, blood loss, cardiac failure etc).

The rete mirabile

The *rete mirabile* (Lat. Id.), 'a wonderful network' is a specific vascular branching type represented with the capillary network enclosed between the vessels of the same type i.e. between the arterioles (in the kidneys) or between the venules (in the liver and the pituitary).

Practice questions

1. What features allow distinguishing systemic and pulmonary circulation routes?
2. What is the difference between arteries and veins with respect to blood flow direction?
3. Discuss Galen's concept of blood circulation.
4. What scientists gave correct description of pulmonary circulation before Harvey's studies?
5. Give the name and publishing year of Harvey's renowned work.
6. Who discovered the capillaries?
7. What layers are distinguishable in the arterial wall?

8. What are the structural features of the muscular, elastic and transitional arteries?

9. Give definition of arterial anastomoses.

10. Name the features of the network-type and the terminal-type arteries.

11. What organs are supplied by the network-type arteries?

12. What organs are supplied by the terminal-type arteries?

13. Name the main distributional regularities of arteries.

14. Discuss the angiogenesis law.

15. Give definition of collateral circulation.

16. Name the scientists who contributed into collateral circulation studies.

17. Discuss how the arteries change after development of collateral circulation.

18. Why is it necessary to know locations of collaterals points of arise and anastomoses areas?

19. Give definition of microcirculation.

20. Name the components of microcirculatory route.

21. Describe the arterioles, the precapillaries, the capillaries, the postcapillaries and the venules.

22. Discuss the function of arteriolovenular anastomoses.

23. Discuss the function of capillaries.

24. Name the functional states of capillaries.

25. Describe the structure of venous wall.

26. Describe structure and function of the venous valves.

27. Name the veins that have most of the valves and the veins that have none.

28. Discuss classification of veins.

29. Describe depot function of veins.

30. Give definition of rete mirabile.

THE HEART, COR

Synonym '**cardia**' gives rise to 'cardiology', 'electrocardiography' and other medical terms.

The *heart*, **cor** is the central circulatory organ. It occupies the middle division of inferior mediastinum yet it is dislocated leftwards so that the two thirds are found to the left from the median line and the rest – to the right. The axis of heart runs from superior to inferior, from anterior to posterior and from right to left. The heart sizes 14Ч10Ч7 cm and weighs about 250-300 grams.

The parts, surfaces and borders of heart

The heart appears as flattened conic body. The external features distinguishable are the base, the apex,

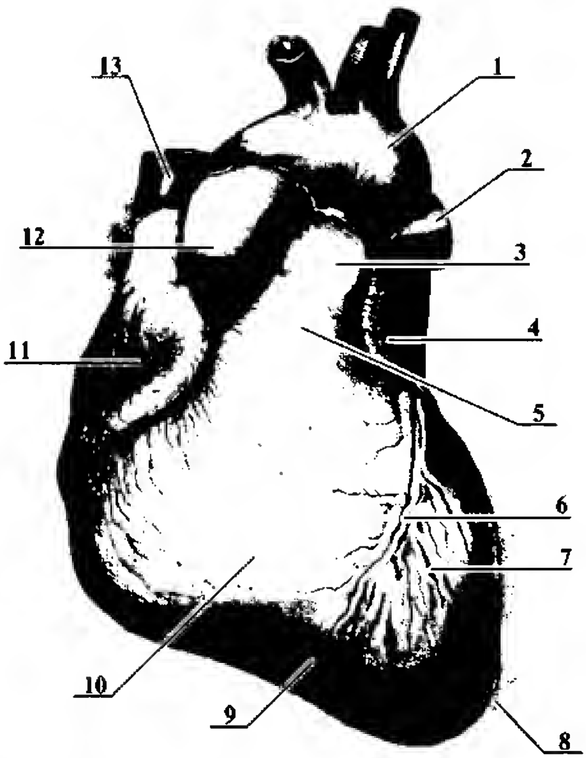


Fig. 74. The heart (anterior surface). 1 – arcus aortae; 2 – a. pulmonalis sinistra; 3 – truncus pulmonalis; 4 – auricula sinistra; 5 – conus arteriosus (infundibulum); 6 – sulcus interventricularis anterior; 7 – ventriculus sinister; 8 – apex cordis; 9 – incisura apicis cordis; 10 – ventriculus dexter; 11 – auricula dextra; 12 – pars ascendens aortae; 13 – v. cava superior.

the anterior (sternocostal) and the diaphragmatic (inferior) surfaces, one border and two pulmonary surfaces — the left and the right (Fig. 74):

- the *base of heart*, **basis cordis** is the upper wider portion of heart. It is directed superiorly, posteriorly and rightwards. The base attaches to large blood vessels;
- the *apex of heart*, **apex cordis** is the lower narrowed and rounded portion directed inferiorly and leftwards. To the right from the apex one can distinguish a small *notch of cardiac apex*, **incisura apicis cordis**;
- the *anterior (sternocostal) surface*, **facies anterior (sternocostalis)** slightly convex, it is directed anteriorly, superiorly and leftwards;
- the *diaphragmatic (inferior) surface*, **facies diaphragmatica (inferior)**[1] is directed inferiorly, posteriorly and rightwards; this surface adheres to the diaphragm;
- the *right border*, **margo dexter** a sharp border that delimits the surfaces on the right; the border is directed inferiorly and rightwards;
- the *left* and *right pulmonary surfaces*, **facies pulmonalis dextra et sinistra** face the respective lungs (Fig. 75).

The sulci of heart

The surface of heart features one transverse and two longitudinal sulci that delimit the cardiac chambers from outside. The sulci contain the blood vessels and fat tissue:

- the *coronary sulcus*, **sulcus coronarius** is a deep circular groove that delimits the atriums and the ventricles. The anterior deeper portion of the groove is covered with the auricles;
- the *anterior interventricular sulcus*, **sulcus interventricularis anterior** runs along the anterior surface of heart. The sulcus delimits the ventricles anteriorly;
- the *posterior interventricular sulcus*, **sulcus interventricularis posterior** runs along the inferior surface of heart. It delimits the ventricles posteriorly.

The sulci join at the notch of cardiac apex.

THE CARDIAC CHAMBERS

The heart features four chambers — two atriums (left and right) and two ventricles (also left and right). The atriums are separated by the *interatrial septum*, **septum interatriale** and the ventricles — by the *interventricular septum*, **septum interventriculare**. The right atrium and the right ventricle constitute the right (venous) part of heart; the left atrium and the left ventricle constitute the left (arterial) part.

The *right atrium*, **atrium dextrum**

The right atrium is a cavity of cubic shape with a well distinguishable

[1] clinical specialists also call it posterior

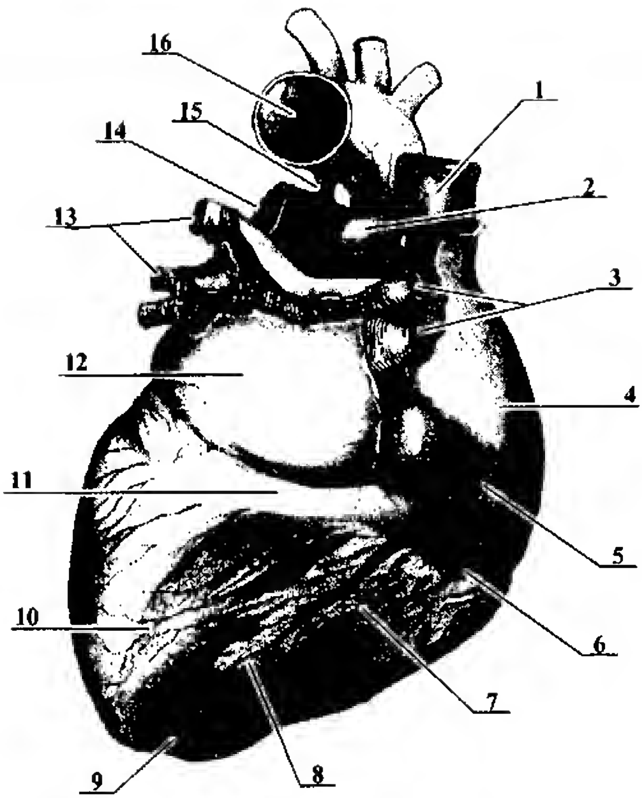


Fig. 75. The heart (posterior surface). 1 — v. cava superior; 2 — a. pulmonalis dextra; 3 — vv. pulmonales dextrae (superior et inferior); 4 — atrium dextrum; 5 — v. cava inferior; 6 — sulcus coronarius; 7 — ventriculus dexter; 8 — sulcus interventricularis posterior; 9 — apex cordis; 10 — ventriculus sinister; 11 — sinus coronarius cordis; 12 — atrium sinistrum; 13 — vv. pulmonales sinistrae (superior et inferior); 14 — a. pulmonalis sinistra; 15 — lig. arteriosum; 16 — aorta.

evagination directed anteromedially — this is the *right auricle*, **auricular dextra** that neighbors the aorta on the right. The auricle is delimited from the venae cavae inlet by the *sulcus terminalis cordis* (Lat. Id.).

The veins that run into the right atrium

These veins are both venae cavae and the coronary sinus:

- the *superior vena cava*, **vena cava superior** opens into the atrium with the *opening of superior vena cava*, **ostium venae cavae superioris**; the opening is found between the superior and the inferior atrium walls;
- the *inferior vena cava*, **vena cava inferior** opens on the posterior wall with the *opening of inferior vena cava*, **ostium venae cavae**;

the opening neighbors the sulcus terminalis. A crescent-shaped fold that expands between the lower *border of opening and the inter-*atrial septum is the *valve of inferior vena cava*, **valvula venae cavae inferioris**[1]. The venous openings are delimited by a small *intervenous tubercle*, **tuberculum intervenosum**. The area that accepts the venae cavae is called the *sinus of venae cavae*, **sinus venarum cavarum**;

- the *coronary sinus*, **sinus coronarius** is the venous collector that drains the cardiac walls. Its opening found in between the atrioventricular orifice and the opening of inferior vena cava is rimmed with a small fold – the *valve of coronary sinus*, **valvula sinus coronarius**[2].

Interior of the right atrium

The internal surface of the right atrium has the features as follows:

- the *fossa ovalis* (Lat. Id.) is a central excavation of the interatrial septum (1.5-2 cm wide). The floor of the fossa is made up of thin endocardial duplication. The fossa is rimmed with the *limbus fossae ovalis* (Lat. Id.). In embryo, the area features the wide opening – the *foramen ovale*, **foramien ovale cordis** that communicates the atriums. Shortly after delivery the foramen closes;
- the *musculi pectinati* (Lat. Id.) are the small muscles situated next to right auricle and the right wall of atrium. The rest of the internal surface of right atrium is smooth.

The *right ventricle*, **ventriculus dexter**

The right ventricle features a cavity of irregular pyramidal shape with anterior, inferior and medial walls distinguishable. A cross-sectioned cavity resembles crescent.

Superiorly, the ventricular cavity communicates with the right atrium via wide *right atrioventricular orifice*, **ostium atrioventriculare dexter**; anteriorly, the ventricle is continuous with the *pulmonary trunk*, **truncus pulmonalis**.

The *tricuspid valve (the right atrioventricular valve)*, **valva tricuspidalis** resides within the right atrioventricular orifice. Its name arises from the number of cusps featured. The valve features the anterior, the posterior and the septal cusps (the valve cusps are irregular in number):

- the *anterior cusp*, **cuspis anterior** resides anteriorly;
- the *posterior cusp*, **cuspis posterior** resides posteriorly;
- the *septal cusp*, **cuspis septalis** is the smallest medial cusp.

The cusps fix firmly to the right fibrous ring that encircles the orifice. The *chordae tendineae* (Lat. Id.) arise from the papillary muscles and the ventricular walls (the latter are the *false chordae tendineae*) and attach to free margins of cusps.

[1] the Eustachian valve
[2] the Thebesian valve

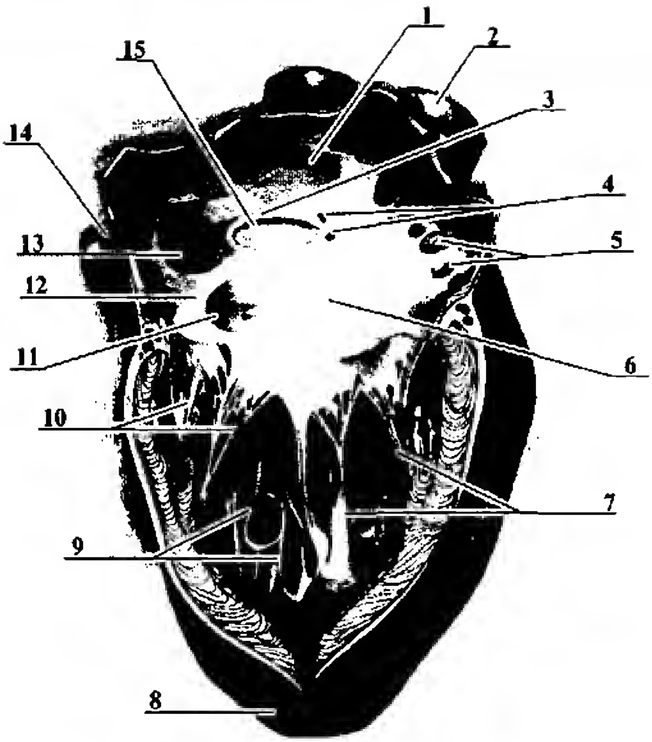


Fig. 76. The right atrium and ventricle. 1 — ostium v. cavae superioris; 2 — aorta; 3 — limbus fossae ovalis; 4 — foramina venarum minimarum; 5 — mm. pectinati; 6 — valva atrioventricularis dextra; 7 — mm. papillares; 8 — apex cordis; 9 — trabeculae carneae; 10 — chordae tendineae; 11 — ostium sinus coronarii cordis; 12 — valvula sinus coronarii cordis; 13 — valvula v. cavae inferioris; 14 — v. cava inferior; 15 — fossa ovalis.

The *papillary muscles,* **musculi papillares** are the conic muscular projections on the internal surface of ventricle. The right ventricle features the muscles as follows:

- the *anterior papillary muscle,* **musculus papillaris anterior** the greatest muscle of the group. It attaches to the anterior and the posterior valve cusps (by means of chordae tendineae);
- the *posterior papillary muscle,* **musculus papillaris posterior** somewhat smaller, it attaches to the anterior and the posterior cusps;
- the *septal papillary muscle,* **musculus septalis papillaris** appears as a group of small muscular projections that attach to the septal and the anterior cusps.

The internal surface of the ventricle features numerous *trabeculae*

carneae (Lat. Id.) that form the networks.

The *conus arteriosus* (Lat. Id.) is the anterosuperior portion of the ventricle with smooth walls. The conus narrows and becomes continuous with the pulmonary trunk. Its opening — the *opening of pulmonary trunk*, **ostium trunci pulmonalis** features the valve.

The *pulmonary valve*, **valve trunci pulmonalis** situated within the opening of pulmonary trunk features three cusps; they appear as three small pouches (Fig. 77):

- the *anterior semilunar cusp*, **valvula semilunaris anterior**;
- the *left semilunar cusp*, **valvula semilunaris sinistra**;
- the *right semilunar cusp*, **valvula semilunaris dextra**;

The spaces bounded by the cusps and the trunk wall are the *sinuses of pulmonary trunk*, **sinus trunci pulmonalis**. Each free margin of the cusp features small *nodules of semilunar cusp*,

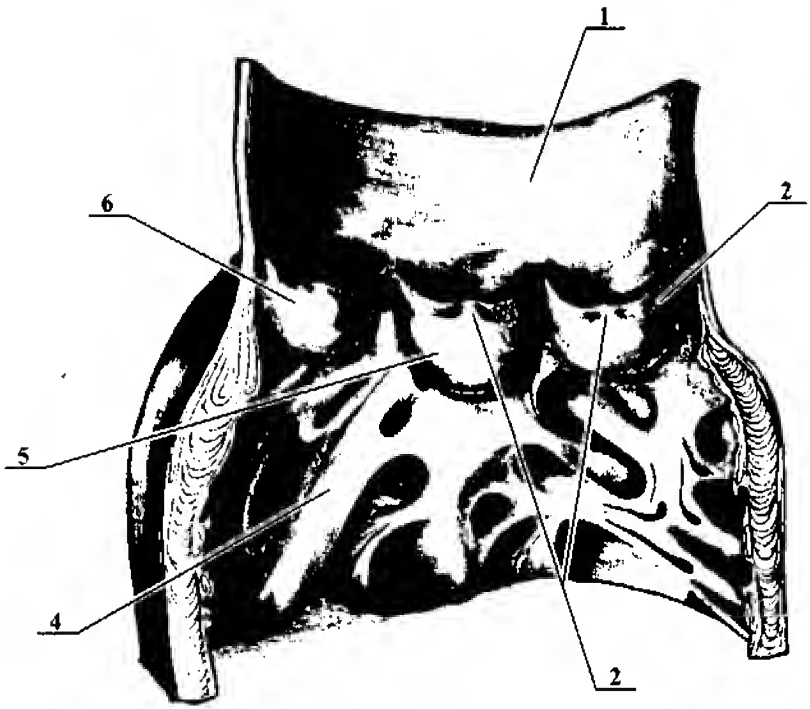


Fig. 77. The semilunar cusps of the pulmonary valve. 1 — truncus pulmonalis; 2 — valvula semilunaris anterior trunci pulmonalis; 3 — nodulus valvularum semilunarium trunci pulmonalis; 4 — ventriculus dexter; 5 — valvula semilunaris sinistra trunci pulmonalis; 6 — valvula semilunaris dextra trunci pulmonalis.

noduli valvularum semilunarium for better cusp contact.

The *left atrium*, **atrium sinistrum**

The space of left atrium is of irregular cubic shape. The anterior wall projection is the *left auricle*, **auricula sisnistra**. The auricle neighbors the pulmonary trunk. The internal surface of auricle features well visible ridges formed of musculi pectinati. The rest of internal surface is smooth. The interatrial septum features the thinner area related to the fossa ovalis.

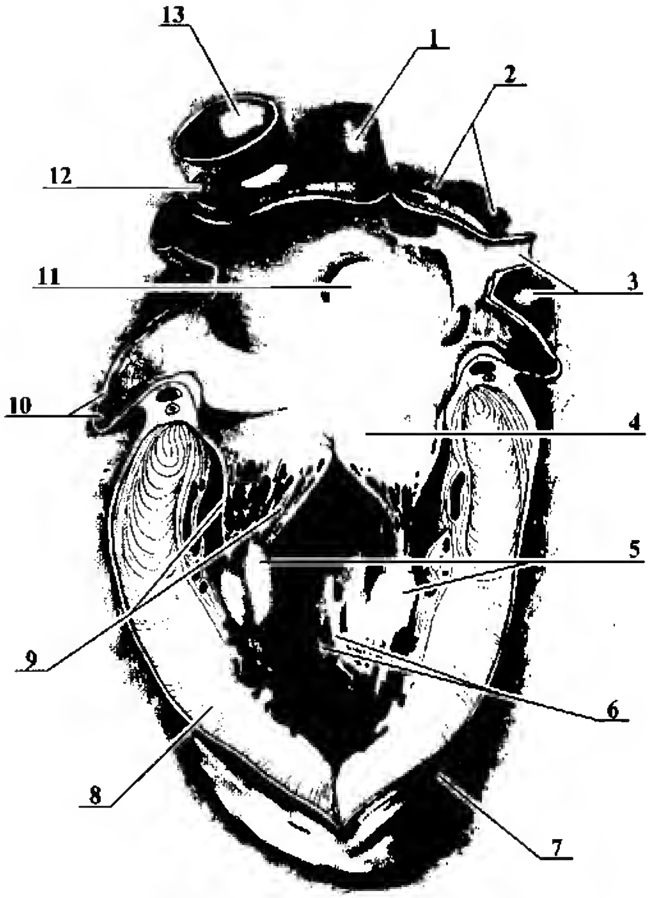


Fig. 78. The left part of heart. 1 — v. cava superior; 2 — vv. pulmonales dextrae (superior et inferior); 3 — vv. pulmonales sinistrae (superior et inferior); 4 — valva atrioventricularis sinistra; 5 — mm. papillares; 6 — trabeculae carneae; 7 — epicardium; 8 — myocardium; 9 — chordae tendineae; 10 — mm. pectinati; 11 — fossa ovalis; 12 — truncus pulmonalis; 13 — aorta.

The pulmonary veins

The left atrium accepts four pulmonary veins (two from each lung) that carry oxygenated blood:

- the *right superior pulmonary vein*, **vena pulmonalis superior dextra**;
- the *right inferior pulmonary vein*, **vena pulmonalis inferior dextra**;
- the *left superior pulmonary vein*, **vena pulmonalis superior sinistra**;
- the *left inferior pulmonary vein*, **vena pulmonalis inferior sinistra**;

The *openings of pulmonary veins*, **ostia venarum pulmonalium** reside on the posterior wall of atrium; the veins lack valves. Sometimes any pair of veins merges to open into the atrium with an unpaired trunk. In this case, the atrium features fewer openings (Fig. 78).

The *left ventricle*, **ventriculus sinister**

The left ventricle features a cone-shaped cavity. Cross-sectioned cavity is of oval shape. The upper portion of the ventricle features two openings – the *left atrioventricular orifice*, **ostium atrioventriculare sinistrum** and the *aortic orifice*, **ostium aortae** (found superiorly and to the right from the left atrioventricular orifice).

The *mitral (left) atrioventricular valve*, **valva atrioventricularis sinistra (valva mitralis)** occupies the respective opening. Because of two cusps present, the valve sometimes is called the bicuspid valve.

The mitral valve features the anterior and the posterior cusps:

- the *anterior cusp*, **cuspis anterior** resides anteriorly and on the right;
- the *posterior cusp*, **cuspis posterior** somewhat smaller, it is found posteriorly and on the left;

The cusps fix firmly to the left fibrous ring that encircles the orifice. The chordae tendineae given by the papillary muscles attach to the free margins of cusps.

The papillary muscles

The left ventricle features two greater papillary muscles – the anterior and the posterior:

- the *anterior papillary muscle*, **musculus papillaris anterior** resides on the anterior ventricular wall;
- the *posterior papillary muscle*, **musculus papillaris posterior** resides on the posterior ventricular wall;

The muscles attach to both cusps by means of chordae tendineae. The internal surface of the ventricle features numerous *trabeculae carneae* (Lat. Id.) that run in all directions and give a reticular look to the inner ventricular surface.

The *aortic valve*, **valva aortae**

The ventricular cavity becomes continuous with the aorta; the *aortic orifice*, **ostium aortae** features the *aortic valve*, **valva aortae**. The valve comprises three semilunar cusps (Fig. 79):

- the *posterior (noncoronary) semilunar cusp*, **valvula semilunaris posterior (valvula non coronaria)**;

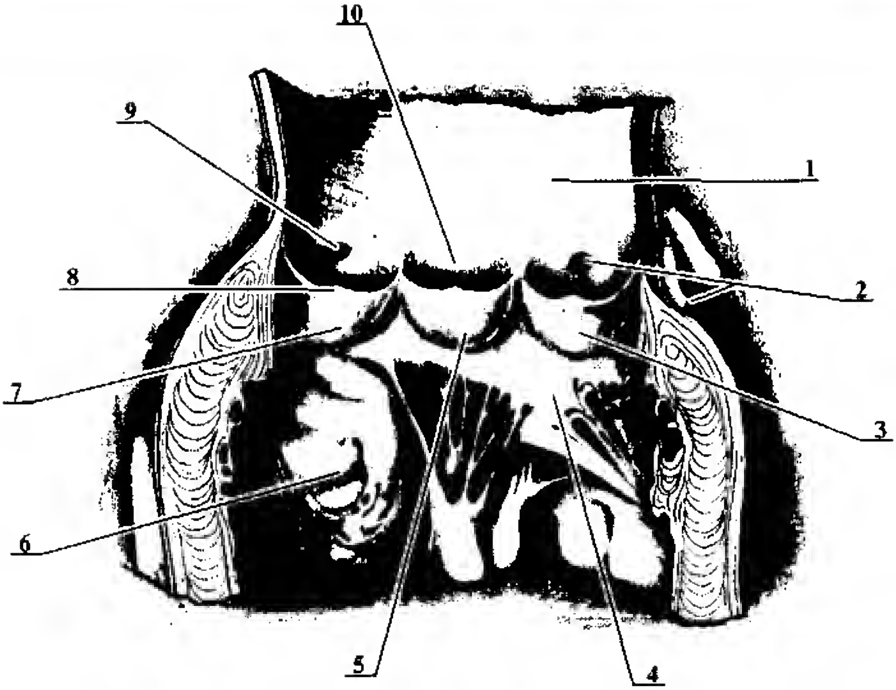


Fig. 79. The semilunar cusps of the aortic valve. 1 – aorta; 2 – a. coronaria sinistra; 3 – valvula semilunaris sinistra aortae; 4 – valva atrioventricularis sinistra; 5 – valvula semilunaris posterior aortae; 6 – ventriculus sinister; 7 – valvula semilunaris dextra aortae; 8 – nodulus valvulae semilunaris aortae; 9 – a. coronaria dextra; 10 – sinus aortae.

- the *left semilunar (coronary) cusp*, **valvula semilunaris (coronaria) sinistra**;
- the *right semilunar (coronary) cusp*, **valvula semilunaris (coronaria) dextra**.

The spaces bounded by the cusps and the aortic wall are the *aortic sinuses*, **sinus aortae**[1]. The right and the left sinuses house the openings of the respective coronary arteries. The free margins of cusps feature *nodules of semilunar cusp*, **noduli valvularum semilunarium**[2]. Laterally from the nodules, one can distinguish thickened areas called the *lunules of semilunar cusps*, **lunulae valvularum semilunarium**.

Clinical applications

The heart valves often undergo pathological alterations. The damaged cusps may fuse or become dense and inflexible. The affected valves produce two common states – valve

[1] Valsalva's sinuses
[2] the nodules of Arantius

insufficiency and stenosis. Insufficiency constitutes incomplete closing of valve cusps followed by blood regurgitation (backflow). Stenosis (narrowing) stands for failure of valve to open completely, which slows the blood flow. Combined pathologies are also of frequent occurrence. The mitral valve is most frequently affected (two thirds of acquired pathologies); the aortic valve occupies the second place in the list. Nowadays, the pathologies are successfully treated by replacement of the valves affected with the artificial valve prostheses (the xenografted valves are also in use).

The *interventricular septum*, **septum interventriculare**

The interventricular septum features the muscular and the membranous parts (Fig. 80):

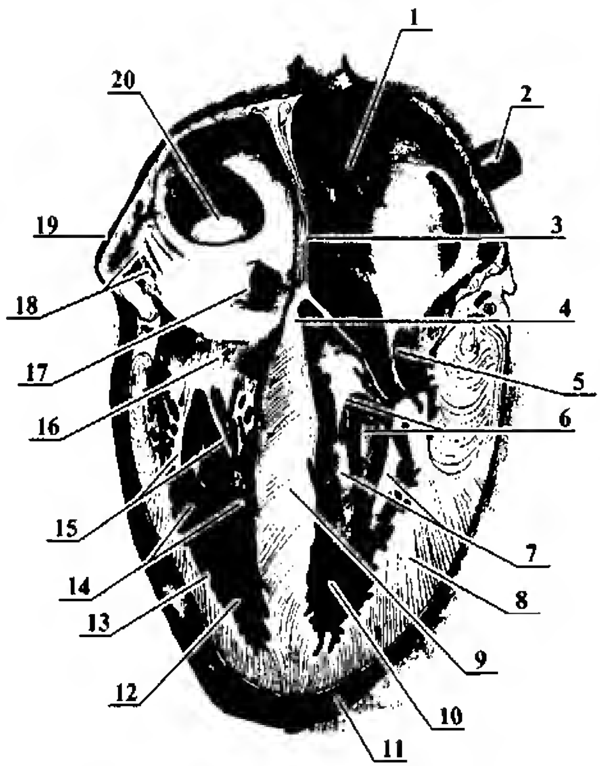


Fig. 80. Longitudinal section of heart. 1 — ostium v. pulmonalis dextra; 2 — v. pulmonalis sinistra; 3 — septum interatriale; 4 — pars membranacea septi interventricularis; 5 — valva atrioventricularis sinistra; 6, 15 — chordae tendineae; 7, 14 — mm. papillares; 8 — myocardium; 9 — pars muscularis septi interventricularis; 10, 12 — trabeculae carneae; 11 — epicardium; 13 — endocardium; 16 — valva atrioventricularis dextra; 17 — ostium sinus coronarii cordis; 18 — mm. pectinati; 19 — auricula dextra; 20 — ostium v. cavae inferioris.

- the *muscular part*, **pars muscularis** is the greater inferior portion formed of thick muscular layer;
- the *membranous part*, **pars membranacea** is the smaller (1 cm long) upper portion formed of fibrous tissue. The membranous part forms during fetal development from fusion of three septa — the interatrial septum, the interventricular septum and the septum of truncus arteriosus[1].

WALL STRUCTURE OF HEART

The wall layers

The cardiac wall consists of three layers — the epicardium, the myocardium and the endocardium:

- the *epicardium* (Lat. Id.) is the external layer represented with visceral plate of cardiac serous coating (the pericardium), immediately below it, one can see fat tissue best developed in the sulci;
- the *myocardium* (Lat. Id.) is the thickest middle layer of heart. The myocardium contains specific muscular bundles of the conductive system of heart;
- the *endocardium* (Lat. Id.) is the internal investment of cardiac chambers. The valves are the endocardial duplications with dense fibrous tissue featured.

The *fibrous rings*, anuli fibrosi

The muscular fibers and the valves attach to the fibrous rings that constitute a dense fibrous skeleton of heart. The heart features four fibrous rings (Fig. 81):

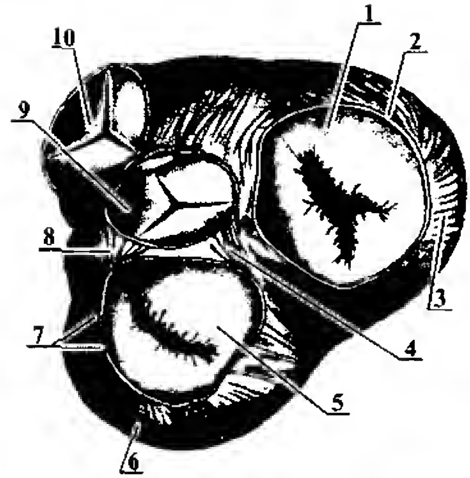


Fig. 81. The fibrous rings. 1 — ostium atrioventriculare dextrum; 2 — anulus fibrosus dexter; 3 — ventriculus dexter; 4 — trigonum fibrosum dextrum; 5 — ostium atrioventriculare sinistrum; 6 — ventriculus sinister; 7 — anulus fibrosus sinister; 8 — trigonum fibrosum sinistrum; 9 — ostium aortae; 10 — ostium trunci pulmonalis.

1) the *left fibrous ring*, **anulus fibrosus sinister** rims the left atrioventricular orifice[2];

2) the *right fibrous ring*, **anulus fibrosus dexter** rims the right atrioventricular orifice;

3) the fibrous ring around the opening of pulmonary trunk;

4) the fibrous ring around the aortic opening.

The left fibrous ring fuses with the aortic ring to give rise to two *left*

[1] this is the common place for septal defects development
[2] large animals like horse or cow feature bone tissue in this area — the os cordis

and *right fibrous trigones*, **trigonum fibrosum dexter et sinister** situated posterior to the aorta. The rings and the trigones separate the atrial myocardium from the ventricular.

The **atrial myocardium** is a thinner (2-3 mm) muscular layer. It arises from the fibrous rings and features two layers – the superficial and the deep. The superficial layer shared by atriums features transverse muscular fibers. In the deep layer, the fibers are longitudinal and circular. The longitudinal fibers prevail; they enfold each atrium separately and form sphincters around venous openings. The longitudinal fibers give rise to muscili pectinati.

The **ventricular myocardium** is thicker than that of atriums. The left ventricle has the thickest muscular layer – about 1.5 cm. The right ventricle wall is somewhat thinner – about 0.7-0.8 cm. The ventricular myocardium comprises complex system of interlaced and looping fibers arranged in three layers:

- the *external (oblique) layer* arises from anterior portion of each fibrous ring; it runs slantwise inferiorly and leftwards to reach the apex. On reaching the apex, the fibers loop to form the *vortex of heart*, **vortex cordis** and become continuous with the *internal longitudinal layer*. The longitudinal layer gives rise to the trabeculae carneae and the papillary muscles. Both layers are shared by the ventricles;
- the *middle layer* comprises transverse fibers that enfold each ventricle separately. This layer is the strongest one.

Nowadays, the cardiac muscular fibers are believed to form the three-dimensional network. Continuous changing of fibers direction provides more efficient force application.

THE CONDUCTING SYSTEM OF HEART

The conducting system of heart comprises specific muscular fibers (light, poor in myofilaments and reach in sarcoplasm) with featured automation i.e. with possibility of generation and transmission of rhythmic impulses to the working myocardium. The system ensures successive contractions (systole) of the atriums and the ventricles. The conducting system features nodes and bundles (the latter conduct the impulses) (Fig. 82).

The *sinu-atrial node*, **nodus sinuatrialis** (node of Keith-Flack) resides within the right atrial wall immediately below the epicardium between the superior vena cava and the right auricle. The node sizes 2X2 mm. the node accepts numerous nerve fibers. The node generates impulses at rate of 60-80 bpm (resting rate); the impulses expand along the bundles to reach the atrial myocardium and the atrioventricular node.

The node is the principal pacemaker (all components of conductive system have pacemaking properties).

The *atrioventricular node*, **nodus atrioventricularis** (node of Aschoff-Tawara) resides right below the endocardium within the upper portion

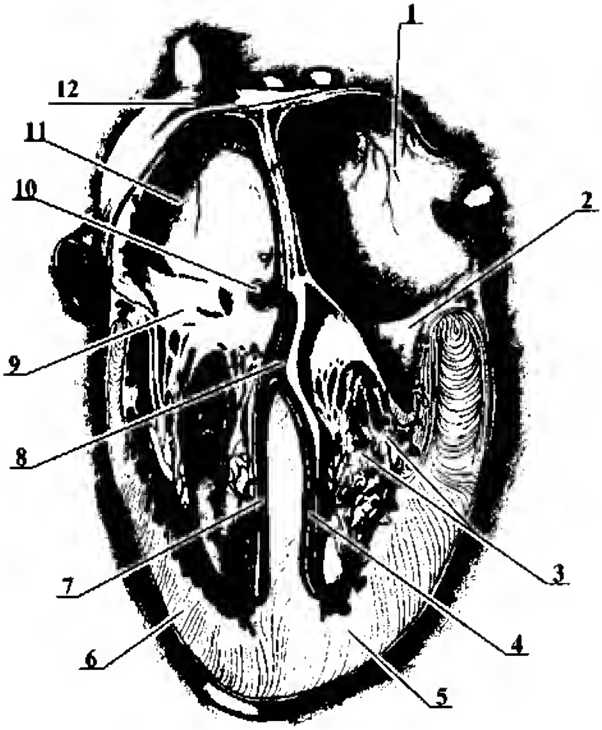


Fig. 82. The conducting system of heart. 1 — atrium sinistrum; 2 — valva atrioventricularis sinistra (v. mitralis); 3 — mm. papillares; 4 — crus dextrum; 5 — ventriculus sinister; 6 — ventriculus dexter; 7 — crus sinistrum; 8 — fasciculus atrioventricularis; 9 — valva atrioventricularis dextra (v. tricuspidalis); 10 — nodus atrioventricularis; 11 — atrium dextrum; 12 — nodus sinuatrialis.

of the interventricular septum on the right. It sizes 5X3 mm. The atrioventricular node is associated with the sinu-atrial node. The atrioventricular node gives rise to the *atrioventricular bundle.*

The *atrioventricular bundle,* **fasciculus atrioventricularis** (the bundle of His) arises from the atrioventricular node, traverses the right fibrous triangle and becomes evident within the interventricular septum as 1 cm long trunk. Within the interventricular septum, the bundle splits into the *left* and the *right bundles,* **crus dextrum et crus sinistrum**. The crura descend below the endocardium on each side of the interventricular septum. The crura split into numerous *subendocardial branches,* **rami subendocardiales** (the fibers of Purkinje) that penetrate the trabeculae carneae, the papillary muscles and working myocardium. The atrioventricular bundle conducts

the impulses from the atriums to the ventricular myocardium.

Clinical applications

Impulses generated by the conducting system of heart can easily be registered by means of ECG. As far as many cardiac diseases are complicated with conductivity disorders, ECG is a very important diagnostic procedure. Myocardial infarction of the interventricular septum (where the atrioventricular bundle passes) is quite dangerous because it causes conductivity block.

THE PERICARDIUM, PERICARDIUM

The heart is enfolded into serous coating called the *serous pericardium*, **pericardium serosum**. The serous pericardium adheres to more dense external layer – the *fibrous pericardium*, **pericardium fibrosum**.

The serous pericardium features two layers with serous cavity between them:

- the *visceral layer*, **lamina visceralis** attaches to the muscular tunic. The visceral layer becomes continuous with the parietal layer at the beginning of great vessels;
- the *parietal layer*, **lamina parietalis** attaches to the fibrous pericardium;
- the *pericardial cavity*, **cavitas pericardiaca** is a closed serous cavity formed of the visceral and the parietal layers of serous pericardium. The cavity contains serous fluid (10-15 ml) that moistens the contacting surfaces. The pericardial cavity features the transverse and the oblique sinuses;
- the *transverse pericardial sinus*, **sinus transversus pericardii** is bounded by the aorta and the pulmonary trunk anteriorly and the superior vena cava and right atrium posteriorly;
- the *oblique pericardial sinus*, **sinus obliquus pericardii** is bounded by the left pulmonary veins and left atrium on the left and the inferior vena cava on the right. Anteriorly, the sinus is bounded by the posterior surface of left atrium and posteriorly – by the pericardium that covers anterior aspect of esophagus.

The *fibrous pericardium* is a dense fibrous capsule that enfolds the heart from outside; its internal surface attaches to the serous pericardium. The entire fibrous pericardium appears as a cone with the base facing the diaphragm. The pericardium is firmly attached to the central tendon of diaphragm. The cone apex neighbors the great vessels also attached to the pericardium (the pericardium is continuous with tunica externa of those vessels). The anterior surface of pericardium is mostly covered by

the lungs; free portion attaches to the sternum and related costal cartilages by means of loose connective tissue. This tissue forms *sternopericardial ligaments*, **ligamenta sternopericardiaca**. Superiorly, the anterior surface of pericardium neighbors the thymus. The lateral surfaces of pericardium attach to the mediastinal pleurae. The posterior surface of fibrous pericardium neighbors the viscera of posterior mediastinum (the thoracic aorta, the esophagus, the azygos and the hemiazygos veins).

TOPOGRAPHY OF HEART

The heart occupies leftmost part of mediastinum. Apart from this, the right atrium and the right ventricle are closer to the anterior thoracic wall while the left atrium and the left ventricle are closer to the posterior mediastinum.

Relations of heart to the anterior thoracic wall

1. The **apex of heart** is related to the V intercostal space 1-1.5 cm medially from the midclavicular line.
2. The **superior boundary** runs horizontally along the upper margins of the cartilages of both III ribs.
3. The **right boundary** runs vertically down from the 3rd to the 5th rib 2 cm away from the right margin of the sternum.
4. The **left boundary** runs slantwise down and laterally from the upper margin of the 3rd rib along the parasternal line to the apex of heart.
5. The **inferior boundary** runs almost transversely and joins the cartilage of right 5th rib and the apex of heart.

Relations of openings

The opening of pulmonary trunk is related to the junction of the left 3rd rib and the sternum. The aortic opening is related to the 3rd intercostal space at the left border of sternum.

The atrioventricular orifices are related to the line that joins the left 3rd costal cartilage with the right 6th costal cartilage. The left orifice is related to the left 3rd costal cartilage and the right orifice — to the right 5th costal cartilage.

Clinical applications

Valve auscultation points do not correspond to the surface mapping points of the cardiac openings. This results from sound conduction within the pertaining soft tissues. The **mitral valve** auscultatory area is related to the apex of heart. The **tricuspid valve** is better heard at the right 5th costal cartilage (namely at the base of xiphoid process). The **aortic valve** auscultatory point is in the right 2nd intercostal space and the **pulmonary valve** point is in the left 2nd intercostal space.

THE CORONARY ARTERIES

Blood supply of the heart is provided by two *left* and *right coronary arteries*, **arteriae coronariae dextra et sinistra**, which arise from respective aortic sinuses (Fig. 83). The arterial openings reside below free cusp margins and thus get blocked at ventricular systole. Ventricular diastole closes the aortic valve and opens the arterial orifices (this mechanism prevents withdrawal of blood from the coronary arteries under higher systolic pressure).

The *left coronary artery*, **arteria coronaria sinistra** (4-6 mm wide and 1-1.5 cm long) arises from the left

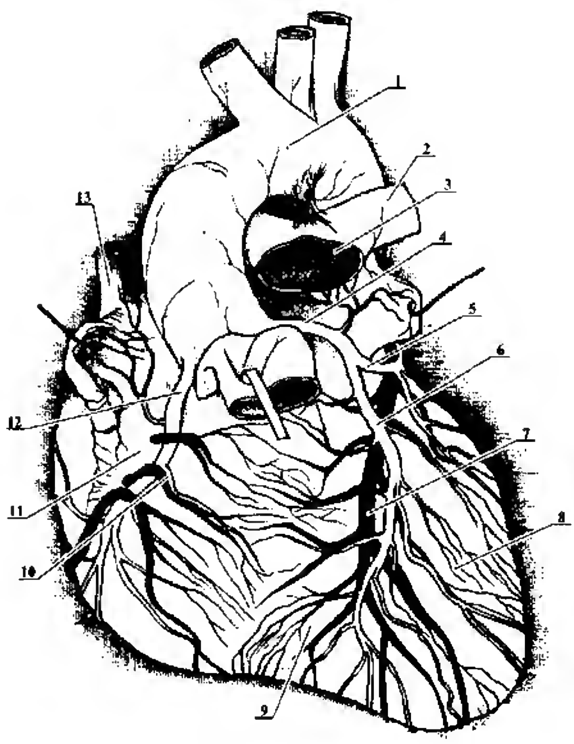


Fig. 83. The cardiac arteries and veins (the anterior surface of heart). 1 — arcus aortae; 2 — a. pulmonalis sinistra; 3 — truncus pulmonalis; 4 — a. coronaria sinistra; 5 — r. circumflexus; 6 — r. interventricularis anterior; 7 — v. cordis magna; 8 — ventriculus sinister; 9 — ventriculus dexter; 10 — v. cordis anterior; 11 — sulcus coronarius; 12 — a. coronaria dextra; 13 — v. cava superior.

coronary sinus and runs between the pulmonary trunk and the left auricle. The principal branches given are the anterior interventricular branch and the circumflex branch.

The *anterior interventricular branch*, **ramus interventricularis anterior** runs along the anterior interventricular sulcus down to the apex of heart where it anastomoses with the posterior interventricular branch of the right coronary artery.

The *circumflex branch*, **ramus circumflexus** enters the coronary sulcus, loops around the left border of heart and terminates on the inferior (posterior) surface where it anastomoses with the right coronary artery.

The left coronary artery supplies the left atrium, the anterior, lateral and most part of the inferior (posterior) surfaces of the left ventricle, two thirds of the interventricular septum and partially the anterior wall of right ventricle.

The *right coronary artery*, **arteria coronaria dextra** (3-5 mm wide) arises from the right coronary sinus and immediately appears within the coronary sulcus. The artery loops around the right border and also terminates on the inferior (posterior) surface where it anastomoses with the left coronary artery. The greatest branch of the right coronary artery is the *posterior interventricular branch*, **ramus interventricularis posterior**, which runs along the sulcus of the same name and anastomoses with the anterior interventricular branch of the left coronary artery.

The right coronary artery supplies the right atrium, a part of the anterior wall and the entire posterior wall of the right ventricle, a part of the posterior wall of left ventricle and posterior one third of the interventricular septum.

Branching variability of the coronary arteries

The coronary arteries feature individual variability yet three common branching patterns are distinguishable. They are the left dominant, the uniform and the right dominant patterns.

The left dominant pattern

The posterior interventricular branch arises from the left coronary artery; it supplies the entire posterior wall of the left ventricle and most part of the posterior wall of right ventricle. The interventricular septum (the area that houses the atrioventricular bundle with related fibers) is supplied by the anterior and the posterior septal branches given solely by the left coronary artery. The left coronary artery thus prevails. This type constitutes about 10% of occurrences.

The uniform pattern

In this case, both arteries feature equal development. The posterior interventricular branch arises from the right coronary artery though the greater portion of the posterior wall of left ventricle is supplied by the circumflex branch of the left coronary artery. The interventricular septum is supplied by the anterior septal branches

of the left coronary artery and by the posterior septal branches of the right coronary artery. This type constitutes about 60% of occurrences.

The right dominant pattern

The posterior interventricular branch arises from the right coronary artery and thus it supplies the most part of the posterior wall of left ventricle. The circumflex branch is small and terminates merely at the left border of heart. The interventricular septum is supplied by both coronary arteries. This type constitutes about 30% of occurrences.

Anastomoses

The branches of coronary arteries form small anastomoses subdivided into intersystem and intrasystem:

- the **intersystem anastomoses** are formed of the branches of the left and the right coronary arteries. These anastomoses reside on the apex of heart, in the posterior portion of coronary sulcus and within the interventricular septum;
- the **intrasystem anastomoses** are formed of the branches given by one and the same coronary artery (either right or left). They are not numerous yet are found in various areas.

Clinical applications

The terminal coronary branches undergo alterations in atherosclerosis. This results in narrowing of vascular lumen and possible impaction of blood clots (thrombosis). Rapid development of thrombosis results in necrosis (myocardial infarction) of the area affected. Minute coronary anastomoses are not capable of full restoration of blood supply.

The individuals with obstructed coronary vessels may undergo a coronary bypass graft. The shunt (a segment of the great saphenous vein or the radial artery) is connected to the ascending aorta and then into the coronary artery distal to the occluded area. Recent modalities include laser destruction of the luminal blockage (with a help of intraluminal catheter) and balloon angioplasty.

THE CARDIAC VEINS

The cardiac veins are subdivided into three groups:

1) the veins related to the coronary sinus (the greatest and numerous);

2) the anterior cardiac veins;

3) the small cardiac veins[1] (Fig. 84).

The *coronary sinus*, **sinus coronaries**[2] is a short (3-5 cm long) though wide venous collector. It resides on

[1] the Thebesian veins
[2] the residual left common cardinal vein

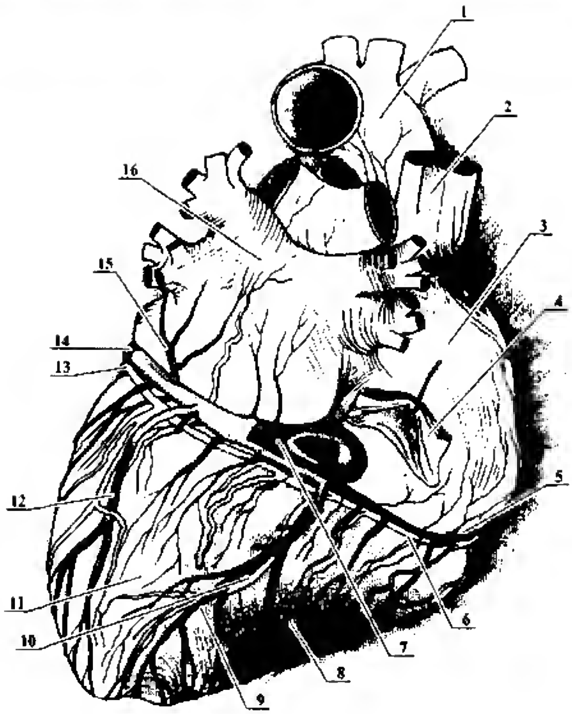


Fig. 84. The cardiac arteries and veins (the posterior surface of heart). 1 — arcus aortae; 2 — v. cava superior; 3 — atrium dextrum; 4 — v. cava inferior; 5 — v. cordis parva; 6 — a. coronaria dextra; 7 — sinus coronarius cordis; 8 — ventriculus dexter; 9 — v. cordis media; 10 — r. interventricularis posterior; 11 — ventriculus sinister; 12 — v. posterior ventriculi sinistri; 13 — a. coronaria sini-stra; 14 — v. cordis magna; 15 — v. obliqua atrii sinistri; 16 — atrium sinistrum.

the posterior surface of heart within the coronary sulcus; the vein opens into the right atrium with the *opening of coronary sinus*, **ostium sinus coronarii** found on the posterior atrial wall. The opening features a small *valve of coronary sinus*, **valvula sinus coronarii**. The sinus drains the veins as follows:

- the *great cardiac vein*, **vena magna cordis** originates in the area of the apex of heart. The vein runs along the anterior interventricular sulcus, turns left and enters the coronary sulcus. The vein loops around the left border of heart and eventually reaches the coronary sinus situated on the posterior surface of heart. The great cardiac vein accepts the *ventricular veins*, **venae ventriculares** (they drain the right and the left ventricles) and the *atrial veins*, **venae atriales** that drain the left atrium;

- the *middle cardiac vein*, **vena cordis media** also originates on the apex of heart. The vein ascends along the posterior interventricular sulcus and joins the coronary sinus next to its opening. The middle cardiac vein accepts the left and the right ventricular veins that drain the posterior walls of both ventricles;
- the *small cardiac veins*, **vena cordis parva** is a small vein situated within the right portion of coronary sinus. The vein originates from the area of right ventricle and runs leftwards to reach the coronary sinus. On the way to destination point, the vein drains several small atrial and ventricular branches;
- the *posterior vein(s) of left ventricle*, **vena(e) ventricui sinistri posterior(es)** originates from several small veins on the posterior surface of left ventricle. It flows either into the coronary sinus or into the terminal portion of great cardiac vein;
- the *oblique vein of left atrium*, **vena obliqua atrii sinistri**[1] runs obliquely along the posterior surface of left ventricle and flows into the coronary sinus next to the great cardiac vein.

The *anterior cardiac veins*, **venae cordis anteriores** are small veins that ascend along the anterior wall of right ventricle. They cross the coronary sulcus and open into the right atrium (i.e. they bypass the coronary sinus).

The *small cardiac veins*, **venae cordis minimae** drain small areas of the right ventricle and the right atrium. They open with numerous *openings of smallest cardiac veins*, **foramina venarum minimarum** into the right atrium and the right ventricle. Most of these veins are of microscopic size.

DEVELOPMENT OF HEART IN HUMANS

Paired mesodermal heart primordia

The heart primordium in humans becomes evident at the 3rd week of embryo's life. It arises from paired mesodermal masses situated below the embryo head. The mesenchyme situated in between the visceral mesoderm and the endoderm gives rise to paired endocardial tubes. The tubes move towards each other and fuse to form a single median heart tube. The heart tube features two well distinguishable layers – the external and the internal. The internal layer is the endocardial plate; it gives rise to the endocardium. The external layer is the epimyocardial plate, which gives rise to both myocardium and epicardium. The paired coelomic

[1] the residual left superior vena cava; it delimits the coronary sinus on the left

cavities fuse to form unpaired pericardial cavity around the cardiac primordium.

The processes listed result in formation of a straight double-layer tube called the *simple tubular heart*, **cor tubulare simplex**.

Compartmentation of tubular heart

In the simple tubular heart, one can distinguish four compartments that correspond to those of inferior invertebrates:

- the *venous sinus*, **sinus venosus** is a thin-walled compartment that accepts the veins;
- the *atrium* (Lat. Id.) resides immediately posterior to the venous sinus;
- the *ventricle*, **ventriculus** resides anterior (cranially) to the atrium. The compartments are delimited by narrowed area, which is the atrioventricular canal;
- the *truncus arteriosus* (Lat. Id.) is the sole blood vessel that arises from the ventricle.

Formation of heart loop

The chief factor to influence heart development is its rapid lengthwise growth. Because of insufficient room, the heart tube first becomes S-shaped and eventually twists into a loop. As far as the cranial end of the tube (the conus arteriosus) remains fixed throughout development of the loop, the atrial compartment displaces posteriorly and superiorly; the ventricle in turn displaces inferiorly and occupies the knee of the loop.

Further, the ventricle exhibits another downward dislocation; both atrium and ventricle thus exhibit consecutive dislocation. The atrium resides dorsally and superiorly and the ventricle – ventrally and inferiorly. This developmental stage is called the *sigmoid heart*, **cor sigmoideum**.

Formation of interatrial septum

The interatrial septum appears at the fourth week of fetal development. It arises from the upper wall of septum and grows anteriorly and downwards in direction of atrioventricular canal. The primary septum is merely a crescent-shaped fold incapable to separate the atriums completely. The primary septum is substituted with the secondary one; it features a wide foramen ovale that communicates the atriums.

Together with the interatrial septum, the atrioventricular canal splits into two atrioventricular orifices. The atrioventricular ridges give rise to both atrioventricular valves. The venous sinus that receives the veins incorporates into the right ventricle wall.

Formation of interventricular septum

The interventricular septum becomes evident at the eighth week of development. It arises from the posteroinferior ventricular wall and grows anteriorly and superiorly to reach the atrioventricular orifices. The septum grows quite rapidly and very soon, the *muscular part* (**pars muscularis**) of interventricular septum becomes dis-

tinguishable; it separates the ventricle into the left and the right chambers yet in the upper portion of the septum one can distinguish the *interventricular foramen* (**foramen Panizzae**) that closes later.

Partitioning of the truncus arteriosus

The truncus arteriosus begins partitioning at the end of the 8th month of development with origination of the spiral fold called the aorticopulmonary septum. Growing, the fold separates the truncus arteriosus into the aorta and the pulmonary trunk.

The semilunar cusps of future valves arise from four endocardial ridges that originate on the border of the truncus arteriosus and the ventricle.

The aorticopulmonary septum expands downwards and joins the main (muscular) part of interventricular septum to form the *membranous part*, **pars membranacea** (and it closes the interventricular foramen). The interventricular septum thus is of dual origin — the greater portion arises from the ventricular myocardium and the lesser one originates from the aorticopulmonary septum.

Heart relocation

The heart primordium originates at the level of cervical vertebrae anterior to the growing pharynx. Further, body growth and elongation of the pharyngeal gut result in caudal dislocation of heart called the *heart descent* (**descensus cordis**). As the result of descent, the heart appears within the thoracic cavity. The nerves already incorporated into the cardiac primordium follow it and that is why the cardiac branches of the vagus nerve and the sympathetic trunk arise from their cervical parts.

DEVELOPMENTAL ANOMALIES OF HEART

Congenital anomalies

Incidence and clinical significance

Because of development complexity, the congenital heart anomalies are of quite frequent occurrence. Rapid development of cardiovascular surgery allows considerable extension of indications for surgical correction of anomalies. In view of this, knowledge on developmental anomalies becomes of great importance. Cardiac surgery of course requires special training yet any specialist must recognize possible heart anomalies in order to direct the individual to a specialized clinic.

The atrial septal defects

Failure of interatrial septum to close constitutes one of the most significant and frequently occurring anomalies. The foramen ovale closes during the first year of life though a small slit-like opening persists in 15-25% of individuals. The opening is symptomless because relatively high blood pressure within the left atrium keeps the fissure closed.

More severe derangements result in persistent large defect. In this case, the oxygenated blood permanently shunts from the left atrium to

the right, which leads to hypertrophy of right atrium (left to right shunt). Large openings require surgery.

The ventricular septal defects

As the membranous part develops separately from the muscular part and is of quite a complex origin, it is a common site of the septal ventricular defects. The size of defects varies from insignificant fissures up to large opening and even complete absence of the septum. The defects may develop independently or occur as a part of more complex congenital heart diseases.

Up to 90% of the defects occur in the membranous part, the rest occupy the muscular (Fig. 85). Surgical treatment is more successful for the high-type defects (related to the membranous part).

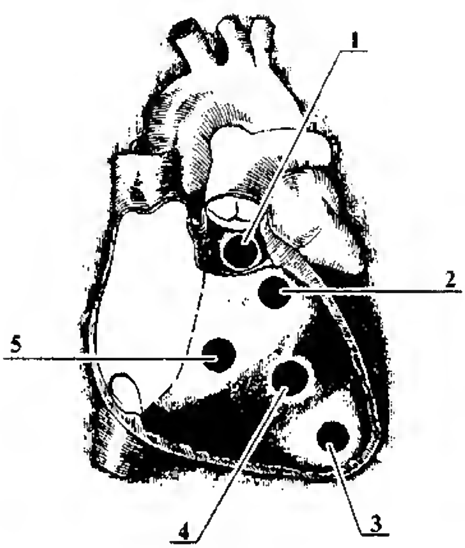


Fig. 85. Variability of septal ventricular defects. 1 – the defect in the muscular part, 2 – the defect below the supraventricular crest, 3 – the apical defect, 4, 5 – the defects in the middle portion of the muscular part.

Derangements in partitioning of truncus arteriosus

Impaired formation of the aorticopulmonary septum may result in variety of congenital anomalies:

- **stenosis of the aorta** – the aorta is well narrowed while the pulmonary trunk is well dilated and opens into both ventricles;
- **stenosis of the pulmonary trunk** on the contrary appears as harsh narrowing of the pulmonary trunk and dilated aorta connected to both ventricles;
- **transposition of the aorta and pulmonary trunk** – here the aorta arises from the right ventricle and the pulmonary trunk – from the left;
- **non-partitioned truncus arteriosus** persists in absence of the aorticopulmonary septum primordium. The vessel maintains connection to both ventricles.

Clinical specialists refer this group to as anomalies of conotruncus; it features wide variety of defects. Being involved into both systemic and pulmonary circulation routes, the derivatives of the truncus arteriosus feature variable abnormality degree: atresia of the pulmonary trunk inlet, origination of one or both pulmonary arteries from the truncus arteriosus, the patent ductus arteriosus etc. In absence of pulmonary arteries, pulmonary circulation

is maintained via patent ductus arteriosus (Fig. 86, 87).

Most of the anomalies that result from deranged partitioning of the truncus arteriosus are complicated with the ventricular septal defects.

Tetralogy of Fallot

This is a combination of four defects as follows:

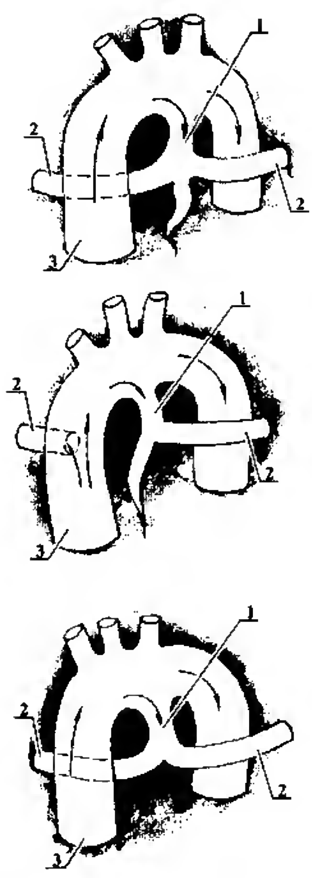


Fig. 86. Pulmonary circulation via patent ductus arteriosus. 1 – the ductus arteriosus, 2 – the pulmonary arteries, 3 – the arterial trunk.

1) pulmonary stenosis;

2) ventricular septal defect;

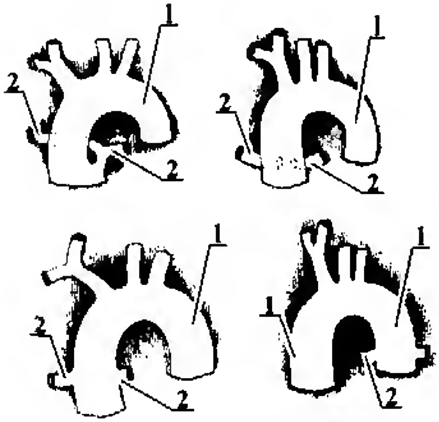
3) overriding aorta (it arises midway between the right and the left ventricles because of origination from the right IV aortic arch);

4) right ventricular hypertrophy.

This anomaly constitutes 14% of all congenital abnormalities. The anomaly immediately causes severe cyanosis because of insufficient blood oxygenation (due to narrowed pulmonary trunk). The ventricular hypertrophy is a secondary condition that results from overload of the right ventricle – it forces the blood via both narrowed pulmonary trunk and the aorta (because it arises from both ventricles).

Rare-type cardiac anomalies

More rare and uncommon anomalies reported in clinical cases are *dex-*



87. Variability of pulmonary arteries origination. 1 – the arterial trunk, 2 – the pulmonary arteries.

trocardia (the apex of heart is directed to the right; it may be associated with *situs inversus*), *heart ectopia* (the heart resides outside the thoracic cavity immediately below skin) and *duplicated heart* (this results from independent development of each cardiac primordium).

Various congenital valvular defects also occur; they result from impaired development of the endocardial ridges.

Clinical applications

Surgical correction is a sole effective method for treatment of congenital anomalies. Heart-lung machine (a special device used for extracorporeal circulation) allows extended surgery on so-called 'dry heart'. Nowadays, various cardiac plastic surgery (and even heart transplantation) is of certain success. Apart from this, palliative surgery is used (that is to improve blood circulation in both circulatory routes).

DEVELOPMENT OF BLOOD VESSELS

Three circulatory routes in fetus

At early stages of development, the fetal circulatory system may be conditionally subdivided into three routes:

- the **intrinsic route** provides circulation within the developing blood vessels;
- the **vitelline route** develops within the yolk sac;
- the **allantoic (umbilical) route** connects the fetal blood vessels to the chorionic capillaries. It transports oxygen and nutrients for developing fetus.

The vitelline route is represented with vitello-mesenteric arteries that arise from the dorsal aorta and with the vitelline veins that drain the yolk sac (they flow into the venous sinus). The vitelline route constitutes phylogeny recapitulation (mammals progenitors featured a large yolk sac to store the nutrient). The vitelline route disappears rapidly; the pertaining vessels transform into the mesenteric arteries and the hepatic portal vein.

The allantoic or umbilical route is associated with paired umbilical arteries that arise from the dorsal aortas. The arteries quit the body and proceed within the umbilical cord to the chorionic villi (for fetal blood oxygenation, because fetal pulmonary system is inactive). The contact area gives rise to the placenta. The umbilical vein (it carries oxygenated blood) is associated with the hepatic vascular system.

As far as the human fetus lacks yolk deposits, the allantoic route originates at early developmental stages and persists throughout of the entire intrauterine period; it is responsible for gas exchange and nourishing of the fetus.

DEVELOPMENT OF THE ARTERIES

The ventral and the dorsal aortas

The primal circulatory system (it well resembles that of inferior vertebrates) begins functioning in the beginning of second month of development. The system features a simple tubular heart continuous with a single truncus arteriosus. The latter gives rise to paired – left and right – ventral aortas that run to the cranial end of the embryo. These aortas become continuous with paired (left and right) dorsal aortas that reach the caudal end of the embryo. Further, the dorsal aortas merge to form a single trunk yet in the cranial end, the dorsal aortas remain paired.

The aortic arches

In the area of lateral pharyngeal wall, the dorsal and the ventral aortas maintain communication via arched anastomoses called the aortic arches (or the branchial arteries). The fetus features six pairs of aortic arches that run within the respective branchial arch but they never arise all at once. The first and the second arches disappear before the caudal arches become evident. The fifth arch is a rudimental one, so it reduces rapidly. Thus, only three pairs (III, IV and VI) continue development.

Transformation of aortic arches

Because of heart descent, both ventral and dorsal aortas elongate and undergo transformation. Some vessels reduce and some exhibit rapid development; the anterior portion of each ventral aorta gives rise to the respective external carotid artery. The internal carotid artery arises from the third aortic arch and the anterior portion of the dorsal aorta; the portion of the dorsal aorta situated in between the third and the fourth arches, gives rise to the common carotid artery. The fourth arches undergo side-dependent changes. The left fourth arch enlarges considerably to become the *arch of aorta* (**arcus aortae**); the arch is continuous with the main trunk of the *dorsal aorta*, which transforms into the *descending aorta* (**aorta descendens**). On the right, the fourth arch gives rise to the proximal portion of the *subclavian artery*; the caudal segment of the arch disappears completely. The left subclavian artery originates from one of the intersegment arteries given by the left dorsal aorta.

The brachiocephalic trunk with related branches (i.e. the right common carotid artery and the right subclavian artery) originates from the segment situated in between the third and the fourth aortic arches on the right. The definitive aorta thus gives rise to the brachiocephalic trunk, the left common carotid artery and the left subclavian artery.

The sixth aortic arch gives rise to the pulmonary arteries that detach from the dorsal aorta and join the pulmonary trunk. The blood from the right ventricle thus reaches the lungs via the pulmonary trunk and the sixths aortic arches.

The Botallo's duct

The right sixth aortic arch detaches from the dorsal aorta and its distal portion reduces.

The left sixth arch maintains communication with the dorsal aorta via wide vessel, which communicates the left pulmonary artery with the aortic isthmus; this communication persists throughout the intrauterine period. This vessel is called the *ductus arteriosus* (Lat. Id. or **ductus Botalli**). It shunts the blood from pulmonary route to the aorta because of inactive lungs in fetus. Shortly after delivery, the ductus closes and transforms into the ligamentum arteriosum.

Development of segmental arteries

The dorsal aortas give rise to paired segment-related arteries that give rise to the arteries of trunk.

The arteries that run dorsally in between the somites are the intersegment dorsal arteries. They give rise to the CNS-related arteries, the vertebral arteries, the posterior intervertebral arteries and the lumbar arteries.

The aorta also gives rise to paired segmental arteries that run laterally in direction of the mesonephros. These arteries mostly reduce (together with the mesonephros) though the arteries related to the gonads, the definitive kidneys and the suprarenal glands continue development.

Initially, the ventral segmental arteries are connected to the yolk sac; later thy transform into unpaired visceral branches – the coeliac trunk, the superior and the inferior mesenteric arteries. Apart from this, the ventral segmental arteries give rise to the umbilical arteries that later move caudally and connect to the internal iliac arteries.

The arteries of limbs incorporate into respective primordia; initially they run coaxially. With development progress, they join the primal vascular plexuses of limbs and form definitive arteries of limbs.

DEVELOPMENT OF THE VEINS

Symmetrical arrangement of the veins

During fetal period, the veins feature symmetrical arrangement similar to that of inferior vertebrates.

The caudal end of embryo features paired posterior cardinal veins; the head and the neck feature anterior cardinal veins, also paired. The anterior and posterior cardinal veins merge on each side to form the common cardinal veins (Couviere's ducts). The common cardinal veins open into the venous sinus. Changes in intrinsic veins mostly deal with development of asymmetric venous trunks found on the right.

Development of the superior vena cava

During fetal period, the left and right anterior cardinal veins communicate via transverse anastomose. Further, this anastomosis gives birth to the left brachiocephalic vein that shunts the blood to the right anterior cardinal vein. Immediately below the anastomosis, the latter enlarges con-

siderably and joins the right common cardinal vein to form the superior vena cava. The segment of the left anterior cardinal vein below this anastomosis reduces; the left common cardinal vein develops into the coronary sinus that drains the principal cardiac veins.

Superior to the anastomosis, both anterior cardinal veins give rise to the internal jugular veins.

Development of the inferior vena cava

The inferior vena cava arises from several primordia. Because of tight association with the mesonephros (which reduces), the posterior cardinal veins also undergo partial reduction. Instead of reduced segments, the longitudinal veins (the subcardinal veins) appear on the medial surface of mesonephros; they form wide anastomoses. The right veins exhibit gradual dilation and elongation; they merge with the vestigial cardinal veins to form a single **inferior vena cava**. The hepatic veins participate in formation of the cranial segment of the inferior vena cava.

Reduced segments of the posterior cardinal veins give rise to the *azygos* **(vena azygos)** and the *hemiazygos* **(vena hemiazygos)** veins.

Development of the hepatic portal vein

The hepatic portal vein arises from vitello-mesenteric veins that initially drain the yolk sac. After the yolk sac disappears, they join the intestines. The growing liver with proper capillary network crosses the vitello-mesenteric veins. The vitello-mesenteric veins thus become interrupted by the hepatic capillary network. After that, blood carried by the vitello-mesenteric arteries passes through the liver. Because of numerous new anastomoses and closure of one of the veins, the hepatic portal vein becomes unpaired.

ANOMALIES OF BLOOD VESSELS

Duplicated aortic arch

This anomaly results from persistent right sixth aortic arch, which normally is absent. The aorta thus features two arches – the left and the right. They encircle the esophagus in ring-shaped manner and actually may compress it and impair food passage. The state requires surgery; one of the arches as a rule is smaller than the opposite so surgery yields a good result.

Dextraposition of the aortic arch

Here, the right sixth aortic arch develops instead of the left one. The left arch becomes the main vessel and joins the dorsal (descending) aorta while the right arch reduces. The ascending aorta thus becomes continuous with the arch that loops around the root of right lung.

Other vascular anomalies

The right subclavian artery sometimes arises directly from the aortic arch or even from the thoracic aorta. In this case, the artery runs posterior to the esophagus; it may impair food passage.

Positional variability of blood vessels so of relatively frequent occurrence; such anomalies have no effect on CVS functioning and become evident during surgery or dissection. During surgical intervention, such anomalies are concern.

Duplicated superior vena cava

Failure of the left anterior cardinal vein to reduce results in development of the left superior vena cava (the vein of Marshall; it constitutes 2-5% of occurrences), which opens either into the coronary sinus or into the left atrium. Association with the coronary sinus is to no effect on hemodynamics. The second case leads to severe hemodynamic disorders because presence of venous blood in the arterial system. In this case, the left brachiocephalic vein is underdeveloped or absent.

Anomalies of the inferior vena cava

Because of development complicity, anomalies of the inferior vena cava are of quite frequent occurrence. The anomalies feature considerable variability (duplicated inferior vena cava, the venous ring next to kidneys, absence of the vein etc.).

FETAL CIRCULATION

As mentioned previously, the fetus develops three circulatory routes – one **intrinsic** and two **extrinsic**: the **vitelline** and the **allantoic (umbilical)**.

In mammals and humans, the vitelline route undergoes rapid involution and the allantoic route continues development.

Formation of placental circulation

In the very beginning of development, the mesoderm around allantois[1] gives rise to the umbilical arteries. They quit the embryo's body and join the chorionic capillary network. The placenta associated with the embryo by means of umbilical veins becomes evident later, at the 2nd month of development. Upon formation of the placental circulation, the fetal blood passes through the placenta, which is in direct contact with mother's blood (the chorionic villi penetrate deep into the functional layer of endometrium and destroy pertaining arteries). The chorionic capillaries are responsible for blood oxygenation and nutrients transporting. Notice that maternal and fetal blood never contact (yet

[1] Allantois (from Greek 'allas' – sausage and 'eidos' – shape) is an outgrowth of the caudal portion of the hindgut; it occupies the embryonic stalk. In humans, the allantois is rudimental while in birds and reptiles it is of great importance for embryo's digestion and withdrawal of waste products

some cases prove the opposite). These two circulatory systems are separated by capillary endothelium.

The nutrients and oxygen thus reach the embryo's body via placental vessels. The placenta is also responsible for withdrawal of fetal waste products.

The umbilical vessels

Paired *umbilical arteries*, **arteriae umbilicales** in fetus arise from the internal iliac arteries. They ascend along the anterior abdominal wall and quit the abdominopelvic cavity via the umbilical ring. Outside the body, they occupy the umbilical cord. The twisted arteries reach the placenta and split into the capillary network. The umbilical arteries carry mixed (both oxygenated and deoxygenated) blood away from the fetus' body. In some cases, only one artery is present.

The oxygenated blood runs back to fetus via a single umbilical vein. It also occupies the umbilical cord and enters the fetus' body via the same umbilical ring.

Topography of umbilical vein

On entering the abdominopelvic cavity, the umbilical vein reaches the liver where occupies the groove on the visceral surface (**sulcus venae umbilicalis**). On reaching the porta hepatis, the vein gives off two branches. The greater branch joins the hepatic portal vein; it carries the arterial blood to the liver. The lesser branch called the *ductus venosus* (Lat. Id. or **ductis Arantii**) joins the inferior vena cava. The arterial blood flows directly into the inferior vena cava via this anastomosis. The portion of blood that passed the liver also reaches the inferior vena cava. The latter carries the venous blood from the lower limbs and lower portion of the trunk. Thus, the segment of inferior vena cava above the hepatic veins and the ductus venosus carries mixed blood.

The liver receives pure arterial blood yet the hepatic portal vein adds a small amount of venous blood to the oxygenated blood. It occurs because of relatively high activity of liver, which is responsible for hemopoiesis.

Circulation within the fetal heart

The inferior vena cava (it carries mixed blood) opens into the right atrium. The latter also receives the superior vena cava (it drains the upper limbs, the head the neck and the anterior thoracic wall). Due to the *valve of inferior vena cava*, **valvula venae cavae inferioris** the blood from inferior vena cava proceeds to the foramen ovale and further to the left ventricle.

From the superior vena cava, the blood proceeds to the right ventricle (via the right atrioventricular foramen) and further to the pulmonary trunk.

Thus, arterial and venous blood, which meet within the right atrium still take different routes and do not mix much. This occurs due to the valve of inferior vena cava, high blood pressure and positional features of the venae cavae. The *intervenous tubercle*, **tuberculum intervenosum** also par-

ticipates in separation of two blood streams.

Significance of the ductus arteriosus

As far as the lungs in fetus are inactive, the pulmonary arteries receive but little blood so the greater portion of the venous blood that enters the pulmonary trunk drains to the aorta via wide ductus arteriosus (Botallo's duct). The latter connects the bifurcation of the pulmonary trunk to the concave portion of the aortic arch (the isthmus).

Why does the upper portion of embryo's body receive more oxygenated blood?

The oxygenated (still mixed) blood that enters the left atrium proceeds to the left ventricle and further to the aorta. Therefore, the areas supplied directly from the aortic arch (the heart, the head and neck and the upper limbs) initially receive more oxygenated blood. This explains relatively greater size of the upper portion of embryo's body.

The aortic segment below the ductus arteriosus receives some venous blood, which reduces oxygen share. The lower portion of the body thus is supplied with low-oxygen blood although it is enough for normal growth and development.

A considerable portion of blood carried by the descending aorta eventually appears within the internal iliac arteries and further within the umbilical arteries, which carry it back to the placenta.

Postnatal changes in circulatory system

Immediately after delivery, the baby gives first cry and the collapsed lungs expand. The pulmonary vessels also expand to receive blood and thus give start to pulmonary circulation. The lungs begin functioning accompanied by intensive pulmonary circulation; the umbilical cord is ligatured and sectioned, which completely terminates placental circulation. Gas exchange appears under full responsibility of lung and the nutrients come from outside.

The umbilical vessels closure occurs during the first week of life; the umbilical vein transforms into peritoneum-enfolded round ligament of liver. The umbilical arteries also close; they transform into the *medial umbilical ligaments*, **ligamenta umbilicales mediales**. The ductus venosus transforms into the *ligamentum venosum* (Lat. Id.) that occupies the fissure on the visceral surface of liver.

Closure of the foramen ovale

With activation of the lungs, the pulmonary veins begin draining the arterial blood to the left atrium, which leads to pressure increase. The vestigial primary interatrial septum thus covers the foramen. Further, the margins of fold and opening fuse to form the complete interatrial septum. Upon closure of foramen, one can distinguish the *fossa ovalis* (Lat. Id.) at that area.

Persistent foramen ovale causes hemodynamic disorders.

Closure of the ductus arteriosus

Intensive circulation within the pulmonary arteries causes the ductus arteriosus to collapse and close during first months of life. The muscular layer keeps the ductus closed until it transforms into a connective band (the *ligamentum arteriosum*) that expands from the bifurcation of pulmonary trunk to the concave part of aortic arch.

Patent ductus arteriosus

This anomaly is of rather frequent occurrence; it causes severe hemodynamic disorders. In this case, the aorta (with relatively high blood pressure maintained) shunts the blood to the pulmonary arteries via patent ductus arteriosus. This results in pressure increase within the pulmonary route and hypertrophy of both ventricles. A share of blood shunted constitutes 40-60% of aortic blood volume. This excessive shunting causes blood deficiency in the descending aorta and reduced blood supply of related organs. This in turn leads to marked growth retardation in children. The state requires surgical intervention — ligaturing and sectioning of the ductus. Surgery brings good results. First operation of such kind was performed in1954.

THE VESSELS OF PULMONARY CIRCULATORY ROUTE

The **pulmonary circulatory route** comprises the blood vessels that carry blood to the lungs for gas exchange and then back to the heart. The route begins from the right ventricle and terminates within the left atrium with four pulmonary veins[1].

THE PULMONARY TRUNK, TRUNCUS PULMONALIS

The pulmonary trunk carries venous blood to the lungs. It arises from the right ventricle (5-6 cm long and 3.5 cm wide) and runs upwards and to the left. Its lower portion neighbors the aorta anteriorly and on the left and the upper portion reaches the aortic arch. There it splits into the *right* and the *left pulmonary arteries* (this is the *bifurcation of pulmonary trunk*).

A connective tissue strand that runs from the bifurcation (or from the beginning of left pulmonary artery) to the aortic arch is the *ligamentum arteriosum*, **ligamentum arteriosum** (6-8 mm long and 3 mm wide). It is an obliterated *ductus arteriosus (the Botallo's duct)*, **ductus arteriosus (Botalli)**[2]. During fetal period, it shunts the blood from the pulmonary trunk to the aorta.

The *right pulmonary artery*, **arteria pulmonalis dextra** is somewhat longer and wider than the left (4-5 cm long, 2-2.5 cm wide). It resides posterior to the ascending aorta and the inferior vena cava (and attaches to the latter). Within the root of lung, the artery resides anteriorly (and below) the main bronchus and above the pulmonary veins. Within the hilum of lung, the artery gives off the branches that proceed to the respective pulmonary lobes.

The shorter and narrower *left pulmonary artery*, **arteria pulmonalis sinistra** (3-3.5 cm long and 2 cm wide) resides below the aorta. Within the root of lung, the artery resides anterior to the left main bronchus. The principal branches of the artery also become evident within the hilum of lung.

[1] regardless of constituents, arteries always carry blood away from heart and veins — in opposite direction

[2] detailed study was made by Fallopius, Arantius and Botallo; the term 'Botallo's duct' is of wide use in clinical practice

The intrinsic divisions of pulmonary arteries

Divisions of both arteries are not fully consistent with those of the bronchi. The branches of each main trunk accompany the lobar and segmental bronchi. Within the segments, the arteries part the bronchi and rapidly split into smaller branches (up to lobular), which become continuous with wide capillaries. The capillaries form a dense network around the alveolus. The capillaries merge into the venules and veins that carry blood away from the lungs. The veins do not accompany the bronchi but run in between the acini, the lobules, the segments and the lobes.

THE PULMONARY VEINS

Each lung features two short (1.5 cm long) but wide pulmonary veins. Within the hilum of lung, the veins reside below the rest of the root constituents.

The **right lung** features two pulmonary veins:

- the *right superior pulmonary vein*, **vena pulmonalis dextra superior** drains the superior and the middle lobes;
- the *right inferior pulmonary vein*, **vena pulmonalis dextra inferior** drains the inferior lobe.

Within the root of lung, both veins reside below the pulmonary artery. On traversing the pericardium, the veins open into the left atrium on its posterior wall.

The **left lung** also features two pulmonary veins:

- the *left superior pulmonary vein*, **vena pulmonalis sinistra superior** drains the superior lobe;
- the *left inferior pulmonary vein*, **vena pulmonalis sinistra inferior** drains the inferior lobe.

Both veins reside below the pulmonary artery and below (but anteriorly) the left main bronchus. The veins run from left to right and traverse the pericardium to open into the left atrium.

Practice questions

1. Name development stages of human heart.
2. Describe topography of heart.
3. Name start and end vessels of the systemic route.
4. Name start and end cardiac chambers of the systemic route.
5. Name start and end vessels of the pulmonary route.
6. Name start and end cardiac chambers of the pulmonary route.
7. Name the principal parts of heart.
8. What sulci demarcate the ventricles?
9. What sulcus demarcates the atriums and the ventricles?
10. Name the surfaces of heart.
11. What cardiac chambers feature the auricles?
12. Name the borders of the heart.
13. Name the parts of the interventricular septum.

14. Name the layers of cardiac wall.
15. What cardiac chamber features the thickest wall?
16. How many muscular layers are distinguishable in the atrial myocardium?
17. How many muscular layers are distinguishable in the ventricular myocardium?
18. Name the insertion point of all myocardial fibers.
19. Where does the vortex of heart reside?
20. Name the cardiac chambers that comprise the papillary muscles.
21. How many papillary muscles are distinguishable within the right ventricle?
22. How many papillary muscles are distinguishable within the left ventricle?
23. Name the cardiac chambers that comprise the musculi pectinati.
24. What cardiac chamber contains the fossa ovalis, the opening of coronary sinus and the valve of inferior vena cava?
25. Name the cardiac opening that features the tricuspid valve.
26. Name the cardiac opening that features the mitral valve.
27. Name the cusps of the right atrioventricular valve.
28. Name the cusps of the left atrioventricular valve.
29. Where do the semilunar cusps reside?
30. What valves have their cusps attached to the chordae tendineae?
31. What area contains the opening of right coronary artery?
32. What area contains the opening of left coronary artery?
33. Name the areas supplied by the left coronary artery.
34. Name the main branch given by the right coronary artery.
35. Name the areas supplied by the right coronary artery.
36. Name the cardiac veins that open into the right atrium directly.
37. Name the cardiac veins drained by the coronary sinus.
38. Where does the sinu-atrial node reside?
39. Where does the atrioventricular node reside?
40. Where does the atrioventricular bundle reside?
41. Name the layers of pericardium.
42. Name the limits of pericardial cavity.
43. Name the pericardial sinuses.
44. What is the average heart weight in males and females?
45. Describe surface relations of the left boundary of heart.
46. Describe surface relations of the right boundary of heart.
47. Describe surface relations of the superior boundary of heart.
48. Describe surface relations of the inferior boundary of heart.
49. Describe surface relations of the apex of heart.
50. Name the auscultatory point for the left atrioventricular valve.
51. Name the auscultatory point for the right atrioventricular valve.
52. Name the auscultatory point for the aortic valve.

53. Name the auscultatory point for the pulmonary valve.
54. Describe surface relations of the aortic and pulmonary valves.
55. Describe surface relations of the mitral and tricuspid valves.
56. Name three main positions of heart with respect to constitutional type of body.
57. Name the organs that receive the most oxygenated blood during embryo's development.
58. What vessels are connected by the ductus arteriosus in fetus?
59. Name the area, where the umbilical vein enters the fetus' body.
60. Describe the pulmonary trunk and its topography.
61. Describe topography of pulmonary arteries
62. Describe intrinsic divisions of the pulmonary arteries.
63. Describe formation and topography of the pulmonary veins.

THE VESSELS OS SYSTEMIC CIRCULATORY ROUTE

The **systemic circulatory route** begins from the left ventricle (with aorta). The aorta gives the arteries to supply the organs with oxygenated blood. The arteries are continuous with the capillary network, which in turn merges into the veins. The veins join the principal venous trunks – the superior and inferior venae cavae. Both venae cavae open into the right atrium. The right atrium also receives the *coronary sinus* – the cardiac venous collector.

THE AORTA, AORTA

The *aorta* (Lat. Id.) is the principal and the greatest (it is about 2.5-3 cm wide) systemic artery. It arises from the left ventricle. In the aorta, one can distinguish three parts – the *ascending aorta*, the *arch of aorta* and the *descending aorta* (Fig. 88).

The *ascending aorta*, **pars ascendens aortae** (6 cm long) ascends rightwards posterior to the pulmonary trunk and to the left from the superior vena cava. The ascending aorta reaches the 2nd right sternocostal joint to become continuous with the arch of aorta. Beginning of the ascending aorta features a dilation called the *aortic bulb*, **bulbus aortae**. This segment houses the aortic valve. Here, the aorta gives the coronary arteries (its sole branches).

The *arch of aorta*, **arcus aortae** begins at the level of sternal angle. It arches superiorly, posteriorly and to the left, and then inferiorly. The convex part is directed superiorly and the concave – inferiorly. On the concave side, one can see the *ligamentum arteriosum*.

On passing over the left main bronchus, the arch of aorta descends to the posterior mediastinum and reaches the body of Th4 on the left. Here it becomes continuous with the descending part of thoracic aorta. Between the two segments, one can see minute narrowing called the *aortic isthmus*, **isthmus aortae**. The isthmus is a developmental feature of aorta; instead of isthmus, *coarctation* (harsh narrowing) of aorta may develop.

The *descending aorta*, **pars descendens aortae** runs along the vertebral column on the left. Its upper portion resides within the posterior mediastinum (the *thoracic aorta*); on passing the *aortic hiatus*, the thoracic aorta becomes continuous with the *abdominal aorta*. The abdominal aorta ends by splitting into common iliac arteries at the level of L4 (the *aortic bifurcation*, **bifurcatio aortae**).

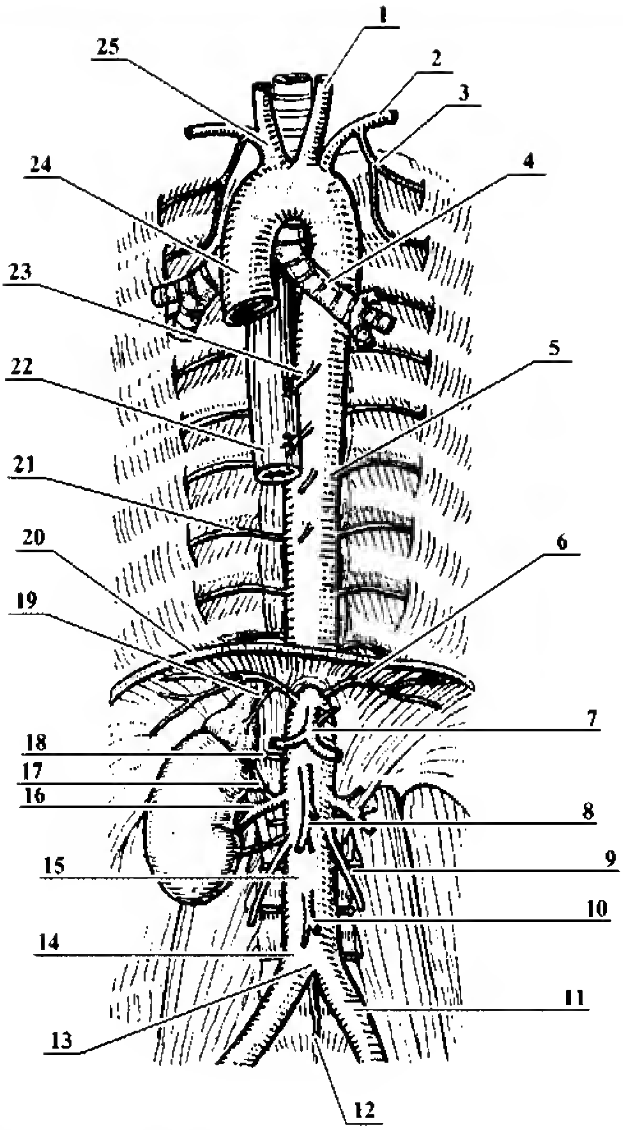


Fig. 88. Branching of the aorta. 1 — a. carotis communis sinistra; 2 — a. subclavia sinistra; 3 — a. intercostalis suprema; 4 — bronchus principalis sinister; 5 — pars thoracica aortae; 6 — a. phrenica inferior; 7 — truncus coeliacus; 8 — a. mesenterica superior; 9 — a. testicularis (ovarica); 10 — a. mesenterica inferior; 11 — a. iliaca communis; 12 — a. sacralis mediana; 13 — bifurcatio aortae; 14 — a. lumbalis; 15 — pars abdominalis aortae; 16 — a.renalis; 17 — a. suprarenalis inferior; 18 — a. suprarenalis media; 19 — a. suprarenalis superior; 20 — m. phrenicus; 21 — a. intercostalis posterior; 22 — oesophagus; 23 — rr. oesophageales; 24 — pars ascendens aortae; 25 — truncus brachiocephalicus; 26 — arcus aortae.

THE BRANCHES OF AORTIC ARCH

The aortic arch gives rise to three great arterial trunks that supply the head, the neck and the upper limbs:

1) the *brachiocephalic trunk*, **truncus braciocephalicus** (3-4 cm long) ascends rightwards, anterior to the trachea. At the level of right sternoclavicular joint, the trunk gives off the *right common carotid artery*, **arteria carotis communis dextra** and the *right subclavian artery*, **arteria subclavia dextra**;

2) the *left common carotid artery*, **arteria carotis communis sinistra** ascends leftwards, anterior to the trachea. On entering the cervical region, the artery runs laterally from the trachea;

3) the *left subclavian artery*, **arteria subclavia sinistra** ascends leftwards, enters the interscalene space and eventually appears within the axillary fossa.

THE COMMON CAROTID ARTERY, ARTERIA CAROTIS COMMUNIS

Relations of the common carotid artery

The right common carotid artery arises from the brachiocephalic trunk at the right sternoclavicular joint; the left common carotid artery arises posterior to the manubrium of sternum, slightly posterior and to the left of the brachiocephalic trunk. Both arteries quit the thoracic cavity via the *thoracic inlet* and ascend laterally from the esophagus and the trachea, within the carotid sheath. Within the sheath, the internal jugular vein passes laterally and anteriorly; the vagus nerve runs in between the vessels. At the level of superior border of thyroid cartilage, each common carotid artery gives off the external and internal carotid arteries.

The carotid sinus

At the *carotid bifurcation*, one can see the dilated area called the *carotid sinus*, **sinus caroticus**; it slightly expands onto the internal carotid artery. Its wall houses numerous nerve terminations from the glossopharyngeal and vagus nerve and from the sympathetic trunk. This area is of a certain importance for blood pressure regulation. Between the arteries, one can see a small (3 mm long) *carotid body*, **glomus caroticum**. The body is the endocrine gland; it is formed of chromaffin tissue.

THE EXTERNAL CAROTID ARTERY, ARTERIA CAROTIS EXTERNA

Relations of the external carotid artery

The external carotid artery ascends medially, immediately below the posterior belly of the digastric and the stylohyoid. The artery traverses the parotid gland and reaches the neck of mandible to give off the branches. The branches given by the external carotid artery are the anterior, medial posterior and terminal (Fig. 89).

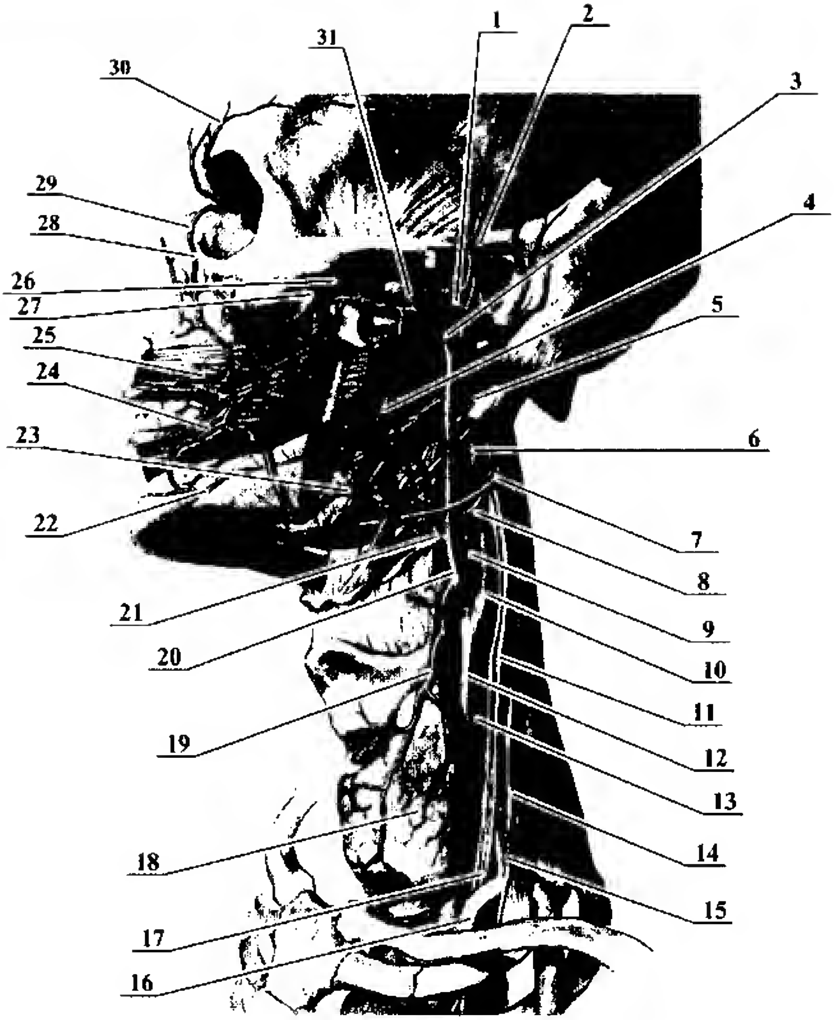


Fig. 89. Arteries of head and neck (lateral aspect). 1 — a. transversa faciei; 2 — a. temporalis superficialis; 3 — a. maxillaris; 4 — a. alveolaris inferior; 5 — a. auricularis posterior; 6 — n. glossopharyngeus; 7 — n. hypoglossus; 8 — a. occipitalis; 9 — a. pharyngea posterior; 10 — a. carotis interna; 11 — n. vagus; 12 — sinus caroticus; 13 — a. carotis communis sinistra; 14 — n. phrenicus; 15 — truncus thyreocervicalis; 16 — a. subclavia sinistra; 17 — a. vertebralis; 18 — glandula thyroidea; 19 — a. thyroidea superior; 20 — a. carotis interna; 21 — a. lingualis; 22 — a. mentalis; 23 — a. facialis; 24 — a. labialis inferior; 25 — a. labialis superior; 26 — a. sphenopalatina; 27 — a. infraorbitalis; 28 — a. angularis; 29 — a. dorsalis nasi; 30 — a. supraorbitalis; 31 — a. meningea media.

The anterior group

The *superior thyroid artery*, **arteria thyroidea superior** arches upwards and then returns to the thyroid gland. Apart from the thyroid gland, the artery supplies the larynx with the *superior laryngeal artery*, **arteria laryngea superior**. This artery traverses the thyrohyoid membrane together with the nerve of the same name and terminates within the laryngeal wall. Some small branches from the superior laryngeal artery supply the hyoid bone and the sternocleidomastoid.

The *lingual artery*, **arteria lingualis** arises at the level of posterior horn of the hyoid bone. The artery occupies the lingual triangle (of Pirogov) immediately below the *hyoglossus*. The terminal branch called the *deep lingual artery*, **arteria profunda linguae** lies deep within the tongue; it gives the *dorsal lingual branches*, **rami dorsales linguae** solely to the dorsum of tongue. Yet within the lingual triangle, the artery gives the branch to the sublingual gland — the *sublingual artery*, **arteria sublingualis**.

The *facial artery*, **arteria facialis** arises somewhat above the lingual artery and neighbors it in the beginning of the way. Then, the artery enters the submandibular gland to give the *glandular branches*, **rami glandulares**. Upon passing the gland, the artery loops around the mandible to reach the facial area. Here it ascends along the anterior border of the masseter in direction of the medial angel of eye. The facial artery gives the following branches:

- the *ascending palatine artery*, **arteria palatina ascendens** supplies the soft palate and the palatine tonsil;
- the *submental artery*, **arteria submentalis** supplies he mental area;
- the *superior* and the *inferior labial arteries*, **arteriae labiales superior et inferior** supply the respective lips;
- the *angular artery*, **arteria angularis** is the terminal segment of the facial artery, which branches within the medial angle of eye. The artery anastomoses with the branches of the *ophthalmic artery*, **arteria ophtalmica**.

The posterior group

The *occipital artery*, **arteria occipitalis** runs posteriorly and superiorly along the posterior belly of the digastric muscle and then passes along the grove of the same name (of the mastoid process of temporal bone), which leads it to the occipital region. The artery supplies the occipital tissues (the *occipital branches*), the auricle (the *auricular branches*), the mastoid process (the *mastoid branch*) and the dura mater of the posterior cranial fossa (the *meningeal branch*).

The *posterior auricular artery*, **arteria auricularis posterior** ascends posterior to the auricle. The artery supplies the auricle (the *auricular branch*), the skin of mastoid and occipital regions, and the tympanic cavity (the *posterior tympanic artery* supplies the tympanic mucosa and the *stapedial branch* supplies the stapedius).

The medial group

This group comprises only the *ascending pharyngeal artery,* **arteria pharyngea ascendens,** a small artery that ascends along the lateral pharyngeal wall. It supplies the pharynx, the soft palate, the tympanic cavity (the *inferior tympanic artery,* it enters the tympanic cavity via the tympanic canaliculus) and the dura mater of posterior cranial fossa (the *posterior meningeal artery).*

The terminal branches

The *superficial temporal artery,* **arteria temporalis superficialis** belongs to the terminal branches of the external carotid artery. In the beginning of its way, it traverses the parotid gland; within the responsibility area, it lies covered by skin and fascia. The superficial temporal artery gives off the *frontal branch,* **ramus frontalis** and the *parietal branch,* **ramus parietalis.** These branches supply the respective regions of head. Apart from this, the artery supplies the parotid gland (with the *parotid branch,* **ramus parotideus),** the facial tissues (with the *transverse facial artery,* **arteria transversa faciei),** the auricle, the external acoustic meatus, the zygomatic bone and the temporal muscle.

The *maxillary artery,* **arteria maxillaris** is the second larger artery of the group. It resides medially from the ramus of mandible. From the origination point, the artery runs slightly upwards and anteriorly (here it passes in between the ramus of mandible and the sphenomandibular ligament) and then enters the infratemporal fossa and further — the pterygopalatine fossa (to reach the latter it passes in between the lateral pterygoid and the temporal muscles). Within the pterygopalatine fossa, the artery gives its terminal branches. The artery is conditionally divided into three segments: the **mandibular** segment situated next to the neck of mandible, the **pterygoid** segment related to the infratemporal fossa and the **pterygopalatine** segment situated within the respective area. The artery gives off numerous branches with the respect to the segments distinguished.

The first segment gives the branches as follows:

- the *inferior alveolar artery,* **arteria alveolaris inferior** occupies the mandibular canal. It supplies the lower teeth and gums; its terminal branch (the *mental branch,* **ramus mentalis)** supplies the mental region and the lower lip;
- the *deep auricular artery,* **arteria auricularis profunda** supplies the temporomandibular joint, the external acoustic meatus and the tympanic membrane;
- the *middle meningeal artery,* **arteria meningea media** enters the cranial cavity via the foramen spinosum and gives the branches to the dura mater of middle cranial fossa; this is the largest dural branch. The middle meningeal artery also gives the *superior tympanic artery,* **arteria tympanica superior;**
- the *anterior tympanic artery,* **arteria tympanica anterior** reaches the

tympanic mucosa via the petrotympanic fissure.

The branches of the second segment are:

- the *superior posterior alveolar artery*, **arteria alveolaris superior posterior** runs to the greater molars and the mucosa of maxillary sinus via the alveolar foramina of the infratemporal surface of maxilla;
- the *muscular branches*, **rami musculares** supply the masticatory muscles and the buccinator.

The third segment gives off three branches:

- the *infra-orbital artery*, **arteria infraorbitalis** enters the orbit via the inferior orbital fissure. Within the orbit, the artery occupies the infraorbital groove and the infra-orbital canal. The infra-orbital artery quits the orbit via the infra-orbital foramen and branches within the soft tissues of the upper lip, the cheek, the nose and the lower eyelid (here it anastomoses with the branches of facial artery). Yet within the infra-orbital canal, the artery gives the *superior anterior alveolar arteries*, **arteriae alveolares superiores anteriores** that supply the upper teeth and gums;
- the *sphenopalatine artery*, **arteria sphenopalatina** enters the nasal cavity via foramen of the same name. it supplies the nasal mucosa;
- the *descending palatine artery*, **arteria palatina descendens** passes within the greater palatine canal; it supplies the entire palate. The artery gives rise to the *artery of pterygoid canal*, **arteria canalis pterygoidei**, which supplies the upper portion of pharynx and the auditory tube.

THE INTERNAL CAROTID ARTERY, A. CAROTIS INTERNA

Relations of the internal carotid artery

The internal carotid artery arises from the common carotid artery. Its proximal portion lies laterally from the external carotid artery; then the artery dislocates medially to appear right anterior to the spinous processes of cervical vertebrae. The artery enters the cranial cavity via the carotid canal where it runs upwards, and then anteriorly and medially. On leaving the canal, the artery passes along the carotid sulcus and enters the cavernous sinus. Within the sinus, the artery forms S-like flexure (a syphon). On leaving the sinus, the artery penetrates the dura mater and gives the terminal fibers.

The parts of the artery

Depending on the area occupied, the artery is divided into four parts as follows;

- the *cervical part*, **pars cervicalis** is the segment that expands from the bifurcation to the external opening of carotid canal;

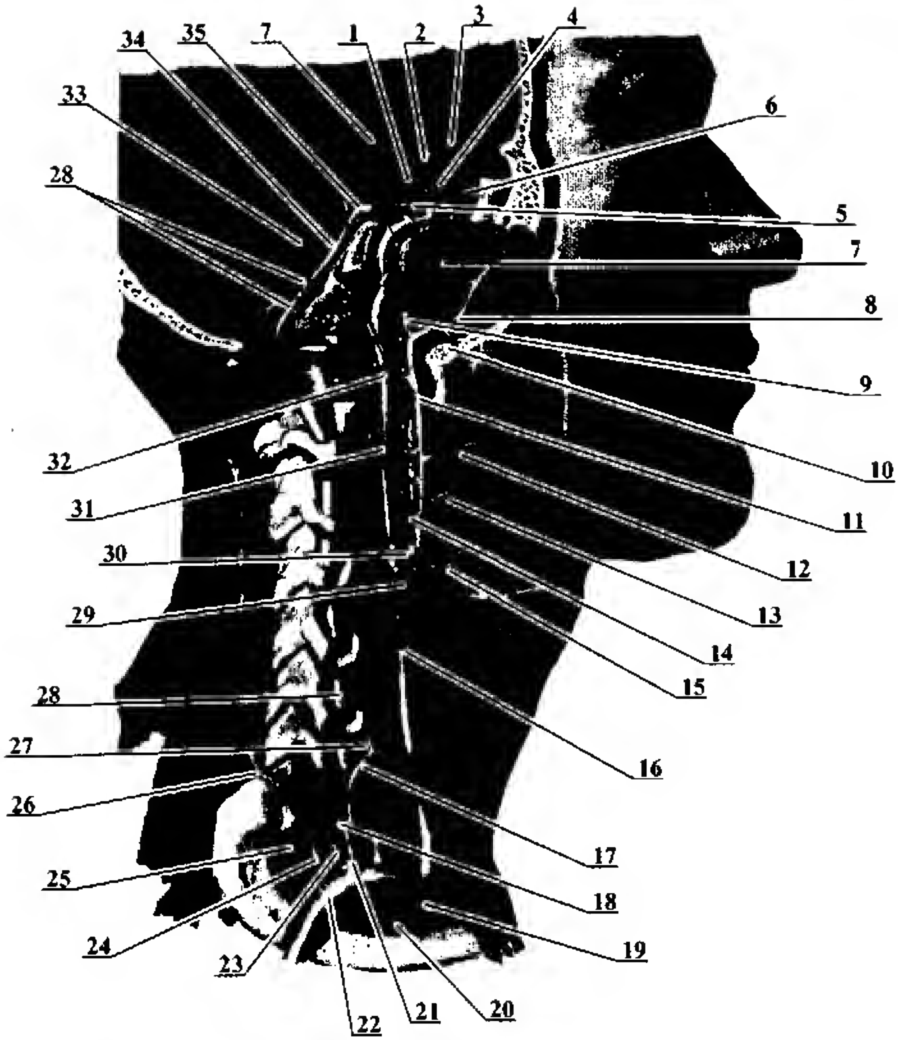


Fig. 90. The cerebral and meningeal arteries. 1 — a. cerebri media; 2 — a. cerebri anterior; 3 — a. communicans anterior; 4 — a. ophthalmica; 5 — a. communicans posterior; 6 — sinus cavernosus; 7 — a. meningea media; 8 — a. maxillaris; 9 — a. temporalis superficialis; 10 — a. alveolaris inferior; 11 — a. carotis externa; 12 — a. facialis; 13 — a. lingualis; 14 — a. pharyngea ascendens; 15 — a. thyroidea superior; 16 — a. carotis communis; 17 — a. thyroidea inferior; 18 — a. transversa colli; 19 — truncus brachiocephalicus; 20 — a. thoracica interna; 21 — truncus thyrocervicalis; 22 — a. subclavia; 23 — a. suprascapularis; 24 — truncus costocervicalis; 25 — a. intercostalis suprema; 26 — a. cervicalis profunda; 27 — a. cervicalis ascendens; 28 — a. vertebralis; 29 — sinus caroticus; 30 — glomus caroticus; 31 — a. occipitalis; 32 — a. auricularis posterior; 33 — a. labyrinthi; 34 — a. basilaris; 35 — a. cerebri posterior.

- the *petrous part*, **pars petrosal** occupies the carotid canal. It gives small branches to the to the tympanic cavity (the *caroticotympanic arteries*);
- the *cavernous part*, **pars cavernosa** is incorporated into the cavernous sinus. Here it features external endothelial investment;
- the *cerebral part*, **pars cerebralis** is the terminal segment that gives the principal branches.

Clinical applications

Stenosis and obstruction of the internal carotid arteries caused by atherosclerosis may result in ischemia of brain and eyes. The state is manifested as cerebral vascular insufficiency (the transient ischemic attack or minor stroke) and vision disorders. The beginning of cervical part is the most susceptible to endothelium lesions that result in such disorders.

The branches of the internal carotid artery

The largest branches of the internal carotid artery are the ophthalmic artery, the anterior and middle cerebral arteries, the posterior communicating artery and the anterior choroidal artery.

The *ophthalmic artery*, **arteria ophtalmica** enters the orbit via the optic canal. In the beginning it runs below the optic nerve and then below it (Fig. 91). Within the orbit, the artery gives the following branches:

- the *central retinal artery*, **arteria centralis retinae** runs within the optic nerve. Together with the nerve, the artery enters the eyeball and terminates within the retina next to optic disc. Its branches are well visible through the ophthalmoscope. The retinal branches undergo alterations in many diseases (hypertonic disease, diabetes mellitus etc.) so examination of retina is of great clinical importance;
- the *posterior ciliary arteries (long and short)*, **arteriae ciliares posteriores (longae et breves)** run along the optic nerve. They traverse the sclera and terminate within the vascular layer of eyeball;
- the *anterior ciliary arteries*, **arteriae ciliares anteriores** enter the anterior portion of eyeball. They supply the sclera and conjunctiva;
- the *lacrimal artery*, **arteria lacrimalis** supplies the lacrimal gland; its terminal branches are the *lateral palpebral arteries*, **arteriae palpebrales anteriores**;
- the *anterior* and *posterior ethmoidal arteries*, **arteriae ethmoidales anteriores et posteriores** leave the orbit via the foramina of the same name. They supply the mucosa of ethmoidal cells and nasal mucosa; the anterior ethmoidal artery gives rise to the *anterior meningeal branch*, **ramus meningeus anterior**;
- the *supra-orbital artery*, **arteria supraorbitalis** leaves the orbit along the supraorbital notch (or via the supraorbital foramen) and gives branches to the frontal area;

- the *supratrochlear artery*, **arteria supratrochlearis** leaves the orbit along the frontal notch and terminates within the frontal area as well.

Apart from the branches listed, the ophthalmic artery supplies the eyelids (with the *medial palpebral arteries*) and the nose (with the *dorsal nasal artery*). The dorsal nasal artery anastomoses with the *angular artery* (given by the facial artery).

The *anterior cerebral artery*, **arteria cerebri anterior** in the beginning of its way runs medially, then superiorly and posteriorly, along the medial surface of hemisphere and above the corpus callosum. The arteries communicate via short anastomo-

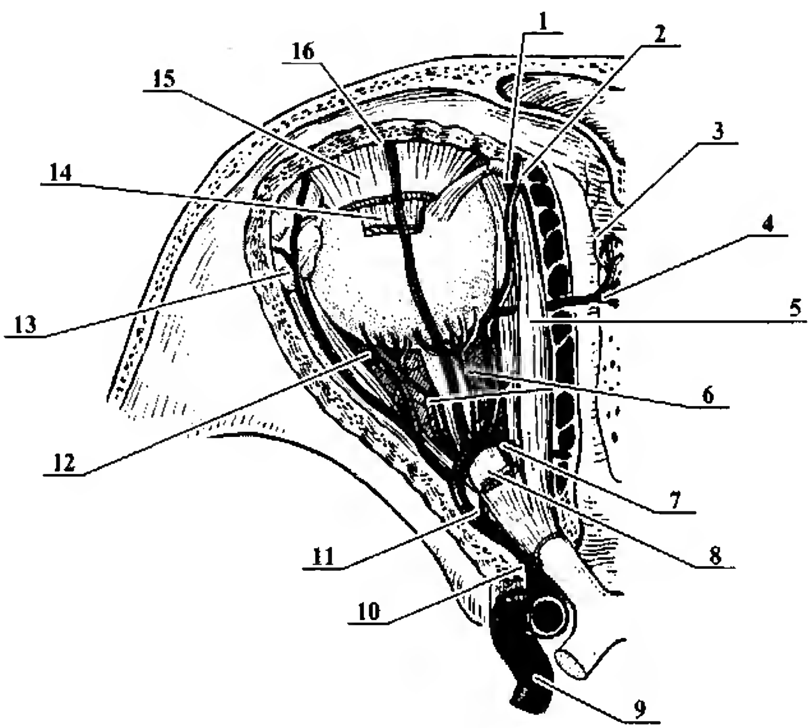


Fig. 91. The arteries of orbit (superior view). 1 — a. dorsalis nasi; 2 — a. supratrochlearis; 3 — a. meningea anterior; 4 — a. ethmoudalis anterior; 5 — m. obliquus superior; 6 — aa. ciliares posteriores breves; 7 — a. ethmoidalis posterior; 8 — n. opticus; 9 — a. carotis interna; 10 — a. ophthalmica; 11 — a. centralis retinae; 12 — a. ciliaris posterior longus; 13 — a. lacrimalis; 14 — m. rectus superior; 15 — m. levator palpebrae superioris; 16 — a. supraorbitalis.

sis visible on the inferior surface of brain — the *anterior communicating artery,* **arteria communicans anterior.**

The *middle cerebral artery,* **arteria cerebri media** is the greatest branch of the internal carotid artery. It runs along the lateral sulcus giving numerous branches.

The *posterior communicating artery,* **arteria communicans posterior** runs posteriorly and joins the posterior cerebral artery (from the *basilar artery,* **arteria basilaris)** (Fig. 92).

The *anterior choroidal artery,* **arteria choroidea anterior** runs along the optic tract to reach the lateral sulcus. There it enters the inferior horn of lateral sulcus and forms the *choroid plexus* of both lateral and third ventricles.

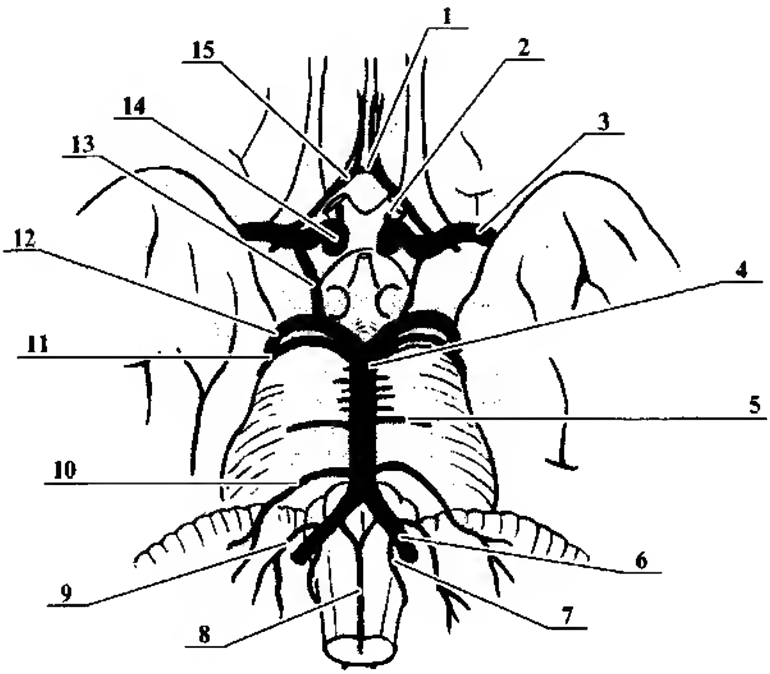


Fig. 92. The cerebral arteries (the inferior surface). 1 — a. communicans anterior; 2 — a. ophthalmica; 3 — a. cerebri media; 4 — a. basilaris; 5 — a. labyrinthi; 6 — a. vertebralis; 7 — a. spinalis posterior; 8 — a. spinalis anterior; 9 — a. cerebelli inferior posterior; 10 — a. cerebelli inferior anterior; 11 — a. cerebelli superior; 12 — a. cerebri posterior; 13 — a. communicans posterior; 14 — a. carotis interna; 15 — a. cerebri anterior.

THE SUBCLAVIAN ARTERY, ARTERIA SUBCLAVIA

Relations of the subclavian artery

The right subclavian artery arises from the brachiocephalic trunk and the left – directly from the aortic arch. The left artery thus is somewhat longer than the right (10 cm vs. 7 cm). Arching superiorly, the artery passes over the cervical pleura and quits the thoracic cavity via the thoracic inlet. Within the cervical region, the artery resides posterior to the vein of the same name and laterally from the trachea and esophagus. Then the artery enters the interscalene space (there it runs along the groove of the first rib). On leaving the space, the artery becomes continuous with the axillary artery; the arteries are delimited by the outer border of the first rib.

Divisions of the subclavian artery

With respect to interscalene space, the subclavian artery is divided into three parts:

1) the part medial to interscalene space;
2) the part in space;
3) the part lateral to space.

The branches of subclavian artery

The first division gives rise to the following branches: the vertebral artery, the internal thoracic artery and the thyrocervical trunk.

The *vertebral artery*, arteria vertebralis

The vertebral artery is the greatest branch of the subclavian artery.

Relations

The artery arises from the superior surface of subclavian artery at the level of C6. It ascends somewhat posteriorly and enters the foramen transversarium of C6; it occupies the canal formed of foramina transversaria of all cervical vertebrae except for C7 (the transverse process of C7 has a groove that passes the beginning of vertebral artery). On leaving the foramen transversarium of C1, the artery proceeds along the *groove for vertebral artery* of the same vertebra and forms a flexure (a syphon). Then the artery traverses the atlantooccipital membrane and enters the cranial cavity via the foramen magnum. On reaching the medullopontine sulcus, the arteries fuse to form the *basilar artery*, **arteria basilaris**.

Divisions of the vertebral artery

The vertebral artery is subdivided into four parts with the respect to area occupied:

- the *prevertebral part*, **pars prevertebralis** is the segment that expands from origination point to the foramen transversarium of C6. This area often experiences sclerotic obstruction, which affects blood supply of brain;

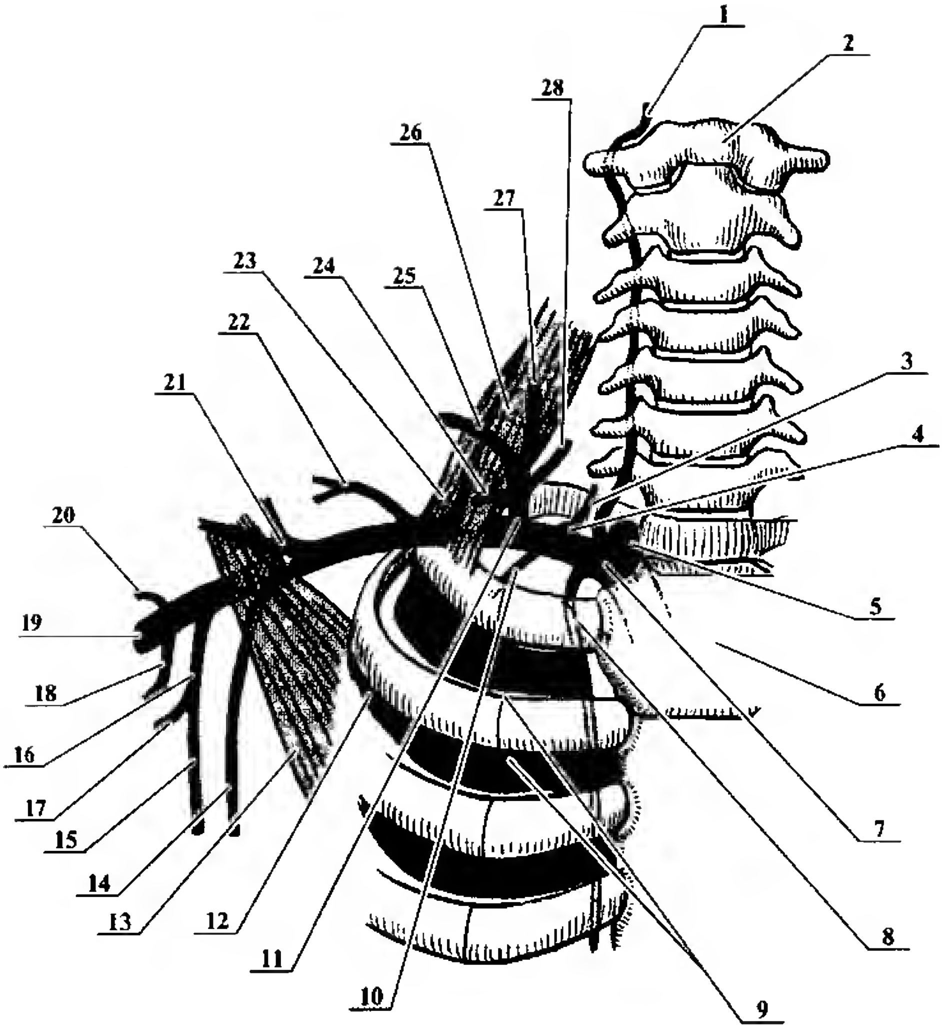


Fig. 93. The subclavian and axillary arteries. 1 — a. vertebralis; 2 — atlas; 3 — a. cervicalis profunda; 4 — truncus costocervicalis; 5 — a. carotis communis dextra; 6 — manubrium sterni; 7 — a. subclavia dextra; 8 — a. thoracica interna; 9 — aa. intercostales anteriores; 10 — a. intercostalis suprema; 11 — truncus thyrocervicalis; 12 — a. intercostalis posterior; 13 — m. pectoralis minor; 14 — a. thoracica lateralis; 15 — a. thoracodorsalis; 16 — a. circumflexa scapulae; 17 — a. subscapularis; 18 — a. circumflexa humeri posterior; 19 — a. brachialis dextra; 20 — a. circumflexa humeri anterior; 21 — a. thoracoacromialis; 22 — a. transversa colli; 23 — m. scalenus medius; 24 — a. suprascapularis; 25 — a. cervicalis superficialis; 26 — m. scalenus anterior; 27 — a. cervicalis ascendens; 28 — a. thyroidea inferior.

- the *cervical part*, **pars transversaria** corresponds to the foramina transversaria of C6 through C2. Here, pathological bony outgrowths may compress the artery;
- the *atlantic part*, **pars atlantica** is related to C1 (its foramen transversarium and the groove for vertebral artery). Here the artery is enclosed into the suboccipital venous plexus;
- the *intracranial part*, **pars intracranialis** resides within the cranial cavity.

The branches of vertebral artery:

- the *spinal branches*, **rami spinales** arise from the cervical part. They enter the vertebral canal via the intervertebral foramina to supply the spinal cord;
- the *muscular branches*, **rami musculares** given by the same part, they supply the deep cervical muscles;
- the *anterior spinal artery*, **arteria spinalis anterior**, paired, is the branch of the intracranial part. Both arteries run medially and then merge midline at the level of decussation of pyramids. The trunk formed descends along the anterior median fissure to terminate at the cauda equina;
- the *posterior spinal artery*, **arteria spinalis posterior**, paired, it descends along the posterior surface of medulla oblongata and then along the posterolateral surface of spinal cord. They also terminate at the cauda equina.

The spinal arteries (two posterior and one anterior) run all along the spinal cord and anastomose with the spinal branches given by the vertebral, intervertebral and the lumbar arteries. It maintains the same lumen diameter all the way down to destination point.

- the *posterior inferior cerebellar artery*, **arteria inferior posterior cerebelli** runs to the inferior surface of the cerebellum.

The *basilar artery*, **arteria basilaris** arises from the vertebral arteries that merge next to the posterior border of the pons. The artery runs along the *basilar sulcus* of pons. On reaching the anterior border of pons, the artery gives its principal branches — the *posterior cerebral arteries*, **arteriae cerebri psoteriores**. The basilar artery also gives the following branches:

- the *anterior inferior cerebellar artery*, **arteria inferior anterior cerebelli** runs to the inferior surface of cerebellum;
- the *superior cerebellar artery*, **arteria superior cerebelli** runs to the superior surface of cerebellum;
- numerous branches to the pons (the *pontine arteries*), to the midbrain (the *mesencephalic arteries*) and to the labyrinth (the *labyrinthine artery*). The latter reaches the labyrinth via the internal acoustic opening (together with the vestibulocochlear nerve);
- the *posterior cerebral artery*, **arteria cerebri posterior** loops around the cerebral peduncles and terminates within the inferior surface of the temporal and parietal lobes.

The *internal thoracic artery*, **arteria thoracica interna**

Relations

The artery arises opposite to the vertebral artery inlet. It descends long the internal surface of thoracic wall 1-2 cm laterally from the sternal border. On reaching the 7th rib, the artery gives its terminal branches – the musculophrenic artery and the superior epigastric artery. It also gives the following branches:

- the *pericardiacophrenic artery*, **arteria pericardiacophrenica** arises from the upper portion of the main trunk. It descends along the phrenic nerve to give the branches to the pericardium and the pleura. Its terminal branches reach the diaphragm. The small pericardial branches anastomose with the coronary arteries. In view of this, numerous but baffled attempts were taken in order to improve blood supply of heart by ligation of the internal thoracic artery below the pericardiacophrenic artery;
- the *anterior intercostal branches* (1-6), **rami intercostales anteriores (I-IV)** run within the intercostal spaces. They anastomose with the posterior intercostal arteries given by the thoracic aorta;
- the *superior epigastric artery*, **arteria epigastrica superior** penetrates the rectus sheath to supply the pertaining area. On reaching the umbilical area, the artery anastomoses with the inferior epigastric artery;
- the *musculophrenic artery*, **arteria musculophrenica** descend along attachment line of diaphragm. It supplies the abdominal muscles, the diaphragm and the intercostal spaces 7 through 11.

Apart from this, the internal thoracic artery supplies the thymus (the *thymic branches*), the thoracic muscles (the *perforating branches*), the mammary gland (the *medial mammary branches*) the bronchi (the *bronchial branches*) and the sternum and mediastinal fat.

The *thyrocervical trunk*, **truncus thyrocervicalis**

The thyrocervical trunk rises next to the medial border of anterior scalene. It is about 3-4 cm long; the branches given are like the following:

- the *inferior thyroid artery*, **arteria thyroidea inferior** the largest branch, it runs superiorly and then medially and inferiorly, and posterior to the common carotid artery. It supplies the thyroid gland, the larynx (the *inferior laryngeal artery*), the pharynx, the esophagus and the trachea;
- the *ascending cervical artery*, **arteria cervicalis ascendens** arises from the main trunk or sometimes from the inferior thyroid artery. It supplies the deep cervical muscles and the spinal cord (the *spinal branches*);
- the *suprascapular artery*, **arteria suprascapularis** runs anterior to the anterior scalene and posterior

to the clavicle. It reaches both supraspinous and infraspinous fossae via the suprascapular notch. It supplies the scapular muscles (here it anastomoses with the *circumflex scapular artery*) and the shoulder joint;

- the *superficial cervical artery*, **arteria cervicalis superficialis** runs above the previous artery. It reaches the lateral cervical region to supply the pertaining muscles (and muscles of back); this artery may be absent (Fig. 93).

The *costocervical trunk*, **truncus costocervicalis**

The costocervical trunk arises from the second part of subclavian artery (within the interscalene space). It gives two branches:

- the *deep cervical artery*, **arteria cervicalis profunda** supplies the deep cervical muscles;
- the *supreme intercostal artery*, **arteria intercostalis suprema** descends anterior to the neck of the first rib. The artery gives rise to the first and the second posterior intercostal arteries.

The *transverse cervical artery*, **arteria transversa colli** arises from the third part of the subclavian artery. It runs laterally traversing the brachial plexus. On reaching the superior angle of scapula, the artery gives two branches: the *ascending branch*, **ramus ascendens** that supplies the cervical muscles and the *descending branch*, **ramus descendens** that runs along the medial border of scapula to supply the muscles and skin of back.

BLOOD SUPPLY OF THE BRAIN

Blood flow in the cerebral vessels is optimized for continuous energy resupply. The brain weight averages 1400 grams (2% of body weight) yet it consumes 20% of oxygen and 17% of glucose intake. The brain however is unable to reserve the oxygen so interrupted blood supply (over 5 minutes) results in irreversible damage to the neurons.

The blood supply of the brain is provided by four great arteries: two internal carotid arteries and two vertebral arteries. They reach the cranial cavity by different routes and form flexures (the syphons). The flexures serve for silencing the pulse wave. Both carotid and vertebral arteries traverse the venous plexuses. A specific wall structure reveals the arteries to be involved into regulation of blood pressure. The brainstem and cerebellum are supplied by the vertebral (and thus basilar) arteries. The cerebral hemispheres receive blood from both internal carotid and vertebral arteries (Fig. 92).

The *anterior cerebral artery*, **arteria cerebri anterior** arises from

the internal carotid artery. It runs anteriorly and medially, superior to the optic nerve. Before entering the longitudinal fissure, the arteries come closer to each other to anastomose by means of short (1-2 mm) *anterior communicating artery*, **arteria communicans anterior**. After anastomosing, the arteries ascend following the genu of corpus callosum and proceed along the medial surfaces of hemispheres to the occipital lobe. The anterior cerebral artery supplies the medial surface of hemisphere up to the parietooccipital sulcus; on the superolateral face, it supplies the superior frontal gyrus and partially the parietal lobe; on the inferior surface, it supplies the medial portions of the orbital gyri.

The *middle cerebral artery*, **arteria cerebri media**, the largest of the group arises from the internal carotid artery and enters the lateral sulcus. There it gives numerous twisted branches. They supply the greater portion of the superolateral face of hemisphere including the frontal, the parietal, the temporal lobes and the insula.

The *posterior cerebral artery*, **arteria cerebri posterior** is the terminal branch of the basilar artery. It ascends posteriorly, loops around the cerebral peduncles and terminates on the inferior surface of brain. The beginning of each artery is connected to the internal carotid artery by means of the *posterior communicating artery*, **arteria communicans posterior** (1-2 cm long). The posterior cerebral artery supplies the inferior surface of temporal lobe and the inferior and medial surfaces of the occipital lobe.

The cerebral arterial circle (of Willis), circulus arteriosus cerebri (Willisii)

The cerebral arteries anastomose to form the arterial ring, which associates two major systems. These anastomoses provide redistribution of blood flow and compensation of restricted blood flow should it occur.

The polygonal circle is formed of the following anastomoses:

1) the anterior cerebral arteries anastomose by means of the anterior communicating artery;

2) each internal carotid artery anastomoses with the respective posterior cerebral artery by means of posterior communicating arteries.

The arterial circle is quite variable. Classic appearance constitutes 30-50% of occurrences; the circle may be open anteriorly and in 6-10% of occurrences, one of the posterior communicating branches may be absent (Fig. 92).

Intrinsic branching of the cerebral arteries

The cerebral arteries form numerous anastomoses on the hemisphere surface forming thus the arterial network. The network gives radiating intrinsic branches to underlying structures. The branches are subdivided into:

1) the short cortical branches that supply the cerebral cortex;

2) the long cerebral branches that reach the white matter.

The basal ganglia and the thalamus receive branches (the central arteries) from the inferior surface of brain.

The intrinsic arteries form few anastomoses. Different sources communicate mainly via microcirculatory network. The network features inability to narrow or widen. Even transient ischemia may result in alteration of capillary endothelium and swelling of glial cells. This may interrupt blood flow within the affected area ("circulation renewal failure" after ischemia).

Clinical applications

The cerebral arteries are susceptible to atherosclerotic lesions. Atherosclerosis causes rupture of blood vessels followed by hemorrhage. Apart from this, atherosclerosis causes obstruction of blood flow, which results in ischemia and necrosis. Slowly progressing atherosclerosis leads to atrophy of cerebral cortex and thus to mental disorders (especially in elderly individuals). Studying of atherosclerosis etiology is one of the greatest medical problems.

THE AXILLARY ARTERY, ARTERIA AXILLARIS

Relations of the axillary artery

The axillary artery is the direct continuation of the subclavian artery; it is continuous with the brachial artery (Fig. 93). The upper boundary of the artery is assigned to the outer border of the first rib; the lower border – to the inferior borders of the pectoralis major (anteriorly) and the latissimus dorsi (posteriorly). The artery occupies the axillary fossa; there it descends posteriorly and laterally from the axillary vein. The axillary artery neighbors the cords of brachial plexus (they run medially, laterally and posteriorly from the vein). With respect to triangles of axillary fossa, the artery is subdivided into three parts.

The part related to the *clavipectoral triangle* gives the following branches:

- the *superior thoracic artery*, **arteria thoracica superior** is a small branch that supplies the intercostal muscles in the first and second intercostal spaces;
- the *thoaco-acromial artery*, **arteria thoracoacromialis** supplies the acromion (the *acromial branch*), the deltoid muscle (the *deltoid branch*) and the pectoralis major (the *pectoral branches*).

The part related to the *pectoral triangle* gives:

- the *lateral thoracic artery*, **arteria thoracica lateralis**, it crosses the axillary vein anteriorly and descends along the serratus anterior. Apart from the serratus anterior, it supplies the mammary gland (the *lateral mammary branches*).

Within the *subpectoral triangle*, the artery gives the branches as follows:

- the *subscapular artery*, **arteria subscapularis** is the greatest branch of the axillary artery. It descends along the inferior border of the subscapularis. The artery gives two terminal branches:

a) the *thoracodorsal artery*, **arteria thoracodorsalis** continues the way along the subscapularis. It supplies the scapular muscles, the latissimus dorsi and the serratus anterior

b) the *circumflex scapular artery*, **arteria circumflexa scapulae** leaves the axillary fossa via the *triangular opening* and reaches the posterior surface of scapula to supply related muscles. The artery anastomoses with the *suprascapular artery* (give by the subclavian artery);

- the *anterior circumflex humeral artery*, **arteria circumflexa humeri anterior**, a small artery that rounds the surgical neck of humerus anteriorly;
- the *posterior circumflex humeral artery*, **arteria circumflexa humeri posterior**, a thicker one, it passes the *quadrangular opening* together with the axillary nerve, rounds the surgical neck posteriorly and terminates within the deltoid; it anastomoses with the anterior circumflex artery. Both circumflex arteries supply the neighboring muscles and the shoulder joint.

THE BRACHIAL ARTERY, ARTERIA BRACHIALIS

Relations of the brachial artery

The brachial artery is a direct continuation of the axillary artery. It joins the neurovascular bundle that runs along the *medial bicipital groove*. On reaching the cubital fossa, the artery gives rise to the radial and ulnar arteries. The greatest branch of the brachial artery is the deep artery of arm (Fig. 94).

The *deep artery of arm* (or the *profunda brachii artery*), **arteria profunda brachii** arises from the upper portion of the brachial artery. It descends posteriorly and enters the radial canal (there it neighbors the radial nerve). It supplies the triceps brachii with numerous muscular branches; apart from this, it gives several terminal branches:

- the *middle collateral artery*, **arteria collateralis media** is the direct continuation of the deep artery of arm. It descends to the lateral epicondyle of humerus where anastomoses with the recurrent interosseous artery;
- the *radial collateral artery*, **arteria collateralis radialis** also reaches the lateral epicondyle to

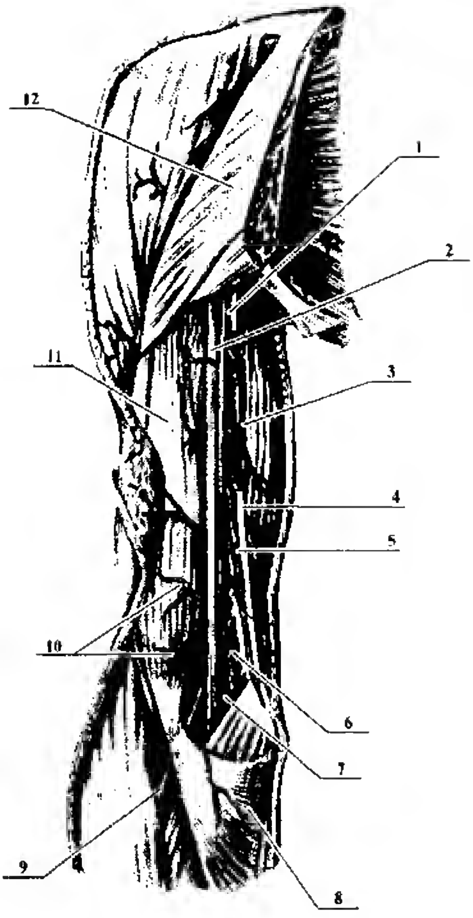


Fig. 94. The right brachial artery. 1 — a. brachialis; 2 — n. medianus; 3 — a. profunda brachii; 4 — n. ulnaris; 5 — a. collateralis ulnaris superior; 6 — a. collateralis ulnaris inferior; 7 — a. ulnaris; 8 — aponeurosis m. bicipitis brachii; 9 — a. radialis; 10 — rr. musculares; 11 — m. biceps brachii; 12 — m. pectoralis major.

anastomose with *recurrent radial artery*;

- the *humeral nutrient artery*, **arteria nutricia humeri** enters the nutrient foramen to supply the humerus.

The *ulnar collateral arteries* arise on the medial aspect of arm:

- the *superior ulnar collateral artery*, **arteria collateralis ulnaris superior** arises from the brachial artery in its middle third and descends along the ulnar nerve. on reaching the *ulnar groove* of humerus, *it anastomoses with the posterior* branch of the *recurrent ulnar artery*;
- the *inferior ulnar collateral artery*, **arteria collateralis ulnaris inferior** arises from the brachial artery immediately above the medial epicondyle. It descends anteriorly to anastomose with the anterior branch of the same *recurrent ulnar artery*.

The ulnar collateral arteries supply the brachial muscles and participate in formation of the arterial network of elbow joint. Apart from this, the brachial artery gives several large *muscular branches*, **rami musculares** to the brachial muscles.

Clinical applications

The deep artery of arm and the ulnar collateral arteries may provide collateral circulation within the upper limb after ligation of the brachial artery below the deep artery of arm. The same action above that deep artery will cause necrosis of the entire limb.

THE RADIAL ARTERY, ARTERIA RADIALIS

Relations of the radial artery

The radial artery occupies the radial groove of forearm together with paired venae comitantes and the superficial branch of radial nerve; there it gives numerous muscular branches. In the lower portion of forearm, the artery is covered with skin and fascia only (Fig. 95). Here, pulsation of artery is palpable. Then the artery declines laterally, passes the "anatomical snuffbox" and finally appears on the dorsal surface of hand. After that, the artery traverses the muscles of first interosseous space of hand and reaches the deep layers of palmar surface. Here it gives rise to the deep palmar arch.

Except for the muscular branches, the artery gives some terminal branches in the forearm:

- the *recurrent radial artery*, **aretria recurrens radialis** arises from the beginning of artery; it ascend laterally to the cubital fossa where anastomoses with the *radial collateral artery* (given by the deep artery of arm);
- the *superficial palmar branch*, **ramus palmaris superficialis**, a thin branch that arises next to the radial styloid process. On the palmar surface of hand it joins the ulnar artery to form the superficial palmar arch;
- the *palmar carpal branch*, **ramus carpalis palmaris** becomes evident in the distal portion of forearm. It

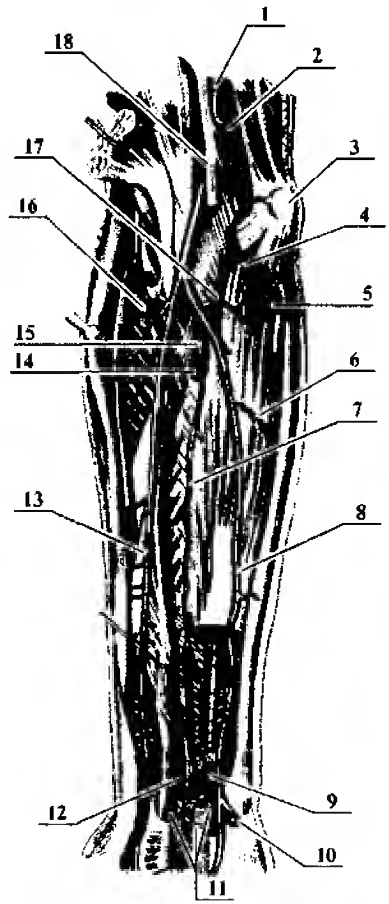


Fig. 95. The arteries of right forearm. 1 – a. brachialis; 2 – a. collateralis ulnaris inferior; 3 – olecranon; 4 – r. anterior a. reccurens ulnaris; 5 – r. posterior a. reccurens ulnaris; 6 – r. muscularis; 7 – a. interossea anterior; 8 – a. ulnaris; 9 – r. carpalis palmaris a. ulnaris; 10 – r. carpalis dorsalis a. ulnaris; 11 – rete carpale palmare; 12 – r. carpalis palmaris a. radiaris; 13 – a. radialis; 14 – a. interossea posterior; 15 – a. interossea communis; 16 – a. reccurens radialis; 17 – a. reccurens ulnaris; 18 – n. medianus.

anastomoses with branch of the ulnar artery participating thus in formation of palmar carpal network;
- the *dorsal carpal branch*, **ramus carpalis dorsalis** passes the "anatomical snuffbox" and appears on the dorsal surface of forearm. It joins the dorsal carpal arch.

The *dorsal carpal arch*, **rete carpale dorsal** resides on the dorsal surface of hand below the extensors tendons. The arch receives the *dorsal car-*

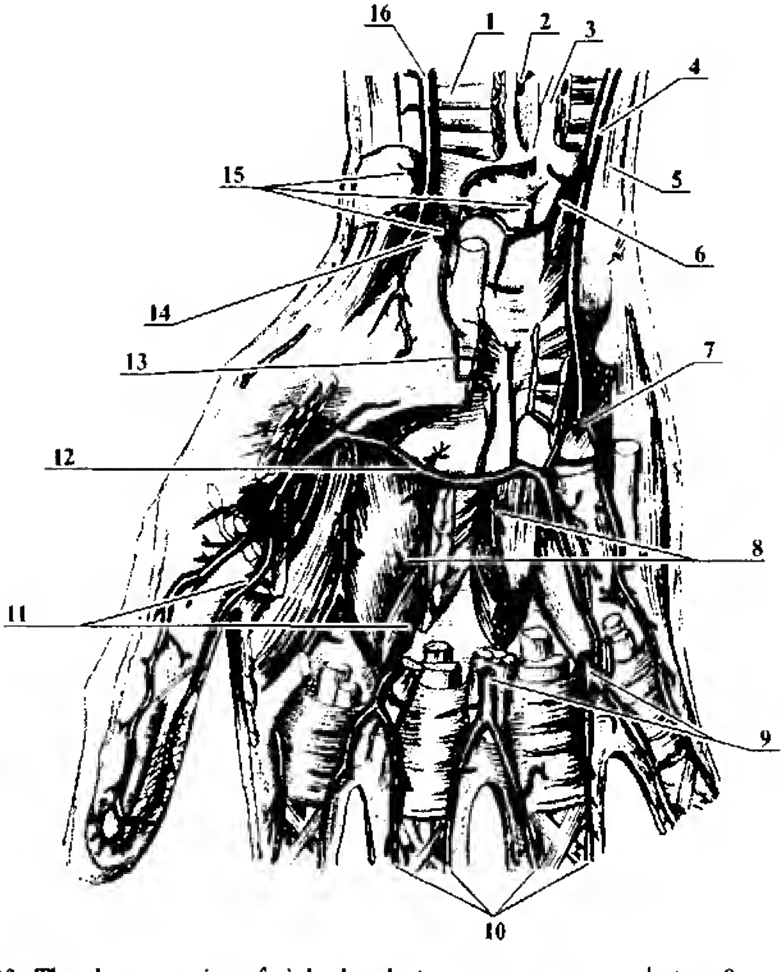


Fig. 96. The deep arteries of right hand. 1 — m. pronator quadratus; 2 — a. interossea anterior; 3 — membrana interossea antebrachii; 4 — a. ulnaris; 5 — m. flexor carpi ulnaris; 6 — r. carpalis palmaris a. ulnaris; 7 — arcus palmaris superficialis; 8 — rr. perforantes; 9 — aa. digitales palmares communes; 10 — aa. digitales palmares proprii; 11 — aa. metacarpeae palmares; 12 — arcus palmaris profundus; 13 — ramus palmaris superficialis; 14 — r. carpalis palmaris a. radialis; 15 — rete carpi palmaris; 16 — a. radialis.

pal branch, **ramus carpalis dorsalis** from the radial artery. Except for the branch mentioned, the arch receives the carpal branch from the ulnar artery and the endings of the interosseous arteries. The arch gives rise to the *dorsal metacarpal arteries*, **arteriae metacarpales dorsales**, which run along the interosseous spaces. On reaching the fingers, they split into thin *dorsa digital arteries,* **arteriae digitales dorsales**.

On the palmar surface, the artery gives the *princeps pollicis artery*, **arteria princeps pollicis** that runs along the first interdigital space. This artery gives proper palmar digital arteries to both aspects of thumb and the *radialis indicis artery*, **arteria radialis indicis** to the forefinger.

On the dorsal surface of hand, the artery gives the first *dorsal metacarpal artery*, **arteria metacarpalis dorsalis** that supplies the lateral aspect of the first finger and the adjacent aspects of the first and second fingers.

The *deep palmar arch*, **arcus palmaris profundus** is formed of the terminal portion of radial artery and the *deep palmar branch*, **ramus palmaris profundus** of the ulnar artery (Fig. 96). The arch resides deep below the tendons of flexors of fingers, on the bases of metacarpal bones. The deep palmar arch gives three *palmar metacarpal arteries*, **arteriae metacarpales palmares**. They run along the interosseous muscles to reach the common palmar digital arteries (around the bases of proximal phalanges). Apart from this, they anastomose with the dorsal metacarpal arteries by means of *perforating branches*, **rami perforantes**.

THE ULNAR ARTERY, ARTERIA ULNARIS

Relations of the ulnar artery

The ulnar artery is the grater branch of the brachial artery. From the origination point, the artery descends medially, traverses the pronator teres and enters the ulnar groove in the lower half of the forearm. Then it descends to the wrist joint together with the ulnar nerve and reaches the hand on passing through the flexor retinaculum. On reaching the middle of hand, it declines laterally to become continuous with the superficial palmar arch.

In the forearm region, the ulnar artery gives the following branches:

- the *ulnar recurrent artery*, **arteria recurrens ulnaris** arises from the beginning of main trunk and ascends to the medial epicondyle. There it splits into the *anterior* and *posterior branches*, **ramus anterior et posterior**, which anastomose with the superior and inferior ulnar collateral arteries;
- the *common interosseous artery*, **arteria interossea communis** a short branch that gives the anterior and

posterior interosseous arteries:

a) the *anterior interosseous artery*, **arteria interossea anterior** runs along the anterior surface of interosseous membrane. On reaching the pronator quadratus, the artery penetrates the membrane and terminates at the dorsal carpal arch. Before entering the dorsal surface of hand, it gives off the palmar carpal branch;

b) the *posterior interosseous artery*, **arteria interossei posterior** penetrates the interosseous membrane immediately upon origination. The artery gives the *recurrent interosseous artery*, **arteria interossea recurrens** that anastomoses with the

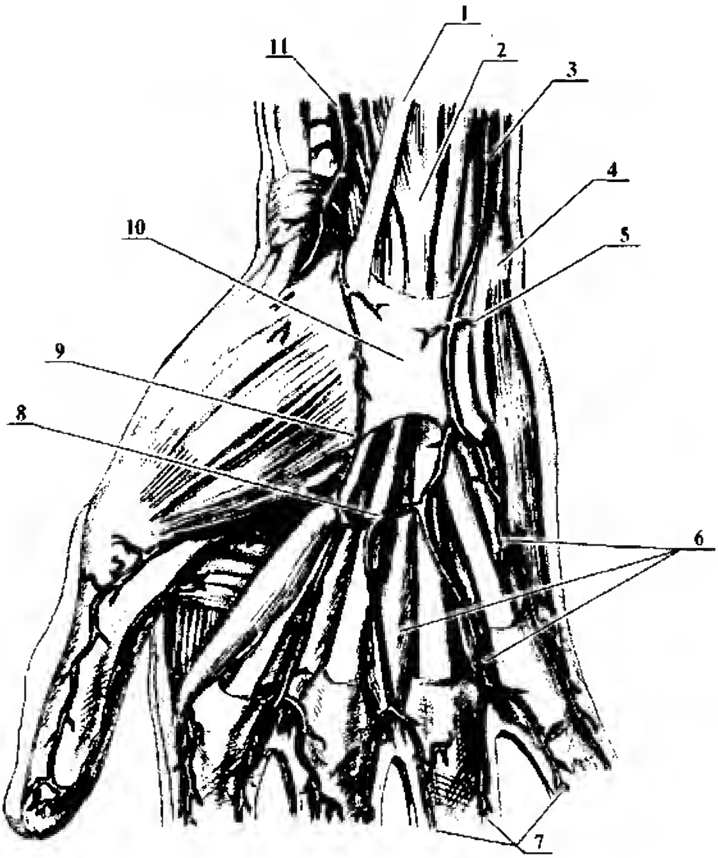


Fig. 97. The arteries of right hand (anterior view). 1 — m. palmaris longus; 2 — m. flexor digitorum superficialis; 3 — a. ulnaris; 4 — os pisiforme; 5 — r. palmaris profundus; 6 — aa. digitales palmares communes; 7 – aa. digitales palmares proprii; 8 — arcus palmaris superficialis; 9 — ramus palmaris superficialis; 10 — retinaculum flexorum; 11 — a. radialis.

middle collateral artery (a branch of the deep artery of arm).

The *palmar carpal arch*, **rete carpi palmare** resides next to the wrist joint and the carpal bones. The arch receives the *palmar carpal branch*, **ramus carpalis palmaris**. The palmar carpal branches given by the radial and the anterior interosseous arteries also participate in formation of the arch. The arch anastomoses with the deep palmar arch.

Within the hand, the artery gives the *deep palmar branch*, **ramus palmaris profundus**. It arises next to the pisiform bone; then it penetrates the muscles of hypothenar and appears below the tendons of flexors. Here it runs laterally and joins the radial artery to form the deep palmar arch.

The *superficial palmar arch*, **arcus palmaris superficialis** resides below the palmar aponeurosis and above the tendons of flexors. The arch is formed of the terminal portion of the ulnar artery and the small branch of the radial artery (the *superficial palmar branch*). The latter branch may be absent; in this case, the arch appears to be open. The arch gives off the *common palmar digital arteries*, **arteriae digitales palmares communes** that neighbor the lumbricals. A next to proximal phalange base, each common artery gives two *proper palmar digital arteries*, **arteriae digitales palmares proprii** (6 branches at all). They run along the adjacent aspects of the fingers 2 through 5. The artery to the ulnar aspect of the small finger arises directly from the ulnar artery (Fig. 97).

THE THORACIC AORTA, PARS THORACICA AORTAE

Relations

The thoracic aorta is a continuation of the aortic arch. It resides within the posterior mediastinum next to the vertebral column. The aorta resides to the left and then posteriorly from the esophagus. The thoracic aorta passes through the aortic hiatus to become continuous with the abdominal aorta. Other neighboring organs are the thoracic duct (found on the left) the azygos and hemiazygos veins and the left sympathetic trunk. The branches of thoracic aorta are subdivided into the parietal and the visceral (Fig. 88).

The parietal branches

The parietal branches are only the posterior intercostal and the superior phrenic arteries:

- the *posterior intercostal arteries*, **arteriae intercostales posteriores** (10 pairs) run along intercostal spaces 3 through 11. The branches running below the 12th rib are the *subcostal arteries*, **arteriae subcostales**. The right arteries are longer than the left ones; they cross the vertebral column. In the beginning, the arteries run within the endothoracic fascia between the

parietal pleura and the internal intercostal membrane nearly in the upper portion of the intercostal spaces. Near the angles of the ribs, the arteries pass between the internal intercostal and the innermost intercostal muscles. At this point, the intercostal arteries pass to and then continue to course within the *costal grooves*, running superior to the intercostal nerves and inferior to the intercostal veins (here they are enfolded by the external and the internal intercostal muscles). The posterior intercostal arteries anastomose with the anterior intercostal branches given by the internal thoracic artery. The intercostal arteries supply the thoracic and the abdominal walls. Each posterior intercostal artery gives off the *dorsal branch*, **ramus dorsalis** that supplies the related areas of back and the spinal cord (with the *spinal branches*, **rami spinales**);

- the *superior phrenic arteries*, **arteriae phrenicae** arise from the lower portion of the thoracic aorta. They supply the lumbar part of diaphragm.

The **visceral branches** supply the thoracic viscera:

- the *bronchial branches*, **rami bronchiales** accompany the bronchi on their way to the lungs. Unlike the vessels of pulmonary route, they are responsible for the nourishing of the lungs. Each bronchus is accompanied by two branches yet one branch may be absent on any side. The bronchial branches anastomose with the branches of pulmonary artery.
- the *esophageal branches*, **rami oesophageales** arise from the anterior surface of the thoracic aorta. The upper esophageal branches anastomose with the inferior thyroid artery and the lower – with the left gastric artery;
- the *pericardial branches*, **rami pericardiaci** are the small branches that reach the posterior surface of pericardium;
- the *mediastinal branches*, **rami mediastinales** are the small branches that supply mediastinal fat.

THE ABDOMINAL AORTA, AORTA ABDOMINALIS

Relations of the abdominal aorta

The abdominal aorta begins its course from the aortic hiatus of the diaphragm and terminates with the aortic bifurcation at L4. The abdominal aorta descends along the left side of vertebral column. The inferior vena cava resides on the right.

The abdominal aorta gives rise to visceral (paired and unpaired) and parietal branches. The unpaired branches are three great arteries: the coeliac trunk, the superior and the

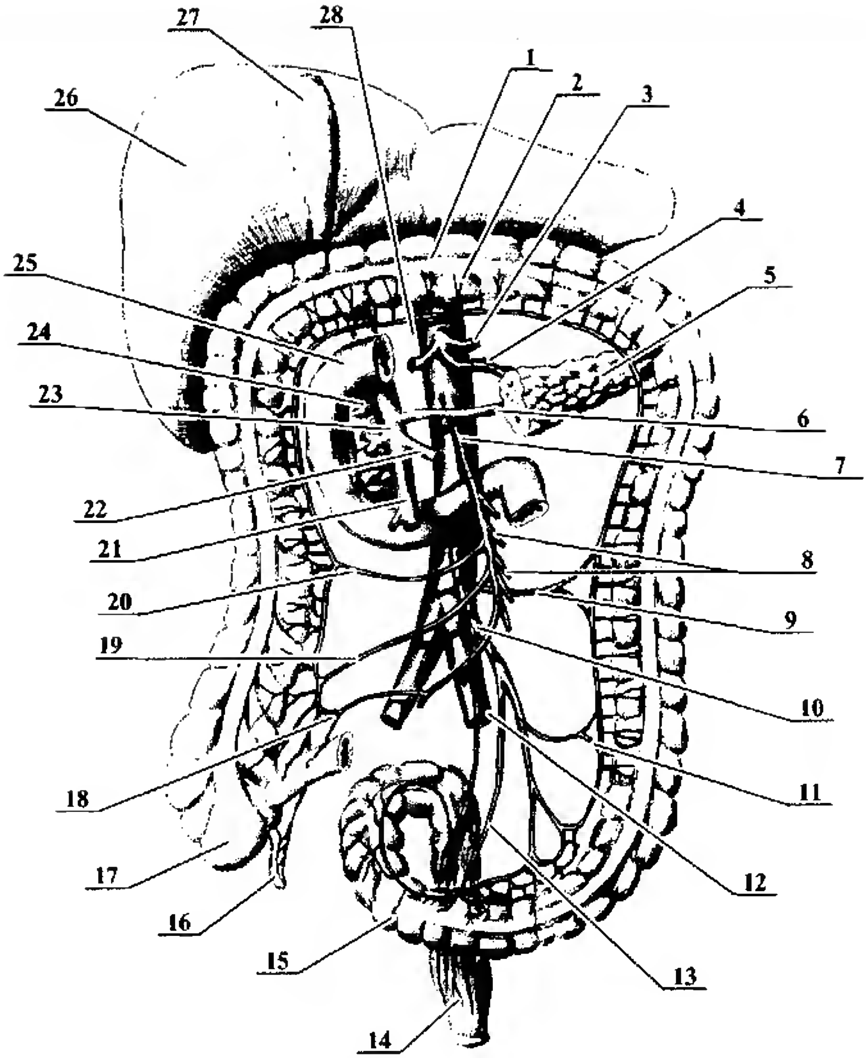


Fig. 98. The branches of abdominal aorta. 1 — colon transversum; 2 — truncus coeliacus; 3 — a. gastrica sinistra; 4 — a. splenica (lienalis); 5 — cauda pancreatis; 6 — v. lienalis; 7 — a. mesenterica superior; 8 — aa. jejunales et ileales; 9 — a. colica sinistra; 10 — a. mesenterica inferior; 11 — a. sigmoidea; 12 — a. iliaca communis; 13 — a. rectalis superior; 14 — rectum; 15 — colon sigmoideum; 16 — a. appendicularis; 17 — caecum; 18 — a. ileocaecalis; 19 — a. colica dextra; 20 — a. colica media; 21 — v. mesenterica superior; 22 — v. mesenterica inferior; 23 — v. porta hepatis; 24 — caput pancreatis; 25 — duodenum; 26 — hepar; 27 — vesica felae; 28 — a. hepatica communis.

inferior mesenteric arteries. Each of them gives rise to individual arterial network (Fig. 98). The paired branches are the renal, the middle suprarenal and the testicular (or ovarian) arteries.

The unpaired visceral branches.

the level of Th12. It appears as thick but short (1-2 cm long) trunk that gives off three branches (this division was called the *Haller's tripod*, **tripus Halleri**): the left gastric, the common hepatic and the splenic arteries (Fig. 99).

thus features anastomoses related to both vertical and horizontal planes.

Clinical applications

The arteries of lower limb are often affected by atherosclerosis and obliterating endarteritis, which feature pathological growth of connective tissue in the inner layer and lipid infiltration of vascular wall. The pathologies result in occlusion of the vessel affected. Collateral circulation may compensate slow progressing occlusion of the distal arteries yet occlusion of min trunks results in severe ischemia and even gangrene. Gangrene requires amputation of the limb. Treatment of the state nowadays includes various reconstructive and plastic surgeries.

THE VEINS OF SYSTEMIC CIRCULATORY ROUTE

The systemic circulatory route comprises three venous systems:

1) the superior vena cava (SVC) system;

2) the inferior vena cava system;

3) the coronary sinus system (the veins of heart).

The SVC system features a specific hepatic portal vein system that carries blood to the liver.

THE SUPERIOR VENA CAVA, VENA CAVA SUPERIOR

Relations of the superior vena cava

The superior vena cava arises from merging left and right *brachiocephalic veins*, **venae brachiocephalicae** posterior to the right first sternocostal joint. The brachiocephalic veins drain the head, the neck and the upper limbs (Fig. 108).

The SVC descends to enter the right atrium at the level of right third intercostal space; the vein is 5-6 cm long and 2.5 cm wide. On the left one can distinguish the ascending aorta and on the right — the mediastinal pleura and phrenic nerve. The right pulmonary vein resides posterior to the SVC and the thymus and right lung — anterior to it. The lower portion of the vein is enfolded into the serous pericardium. The VSC receives the azygos vein that rounds the root of right lung and passes from superior to inferior and from posterior to anterior.

THE BRACHIOCEPHALIC VEIN, VENA BRACHIOCEPHALICA

Relations of the brachiocephalic vein

Each brachiocephalic vein is formed of the internal jugular and the subclavian veins. The junction point is situated posterior to the respective sternoclavicular joint. The right vein is shorter than the right (2-3 cm); it runs vertically down. The left vein is about twice as longer (4-5 cm); it slants down and rightwards to join the right vein.

The tributaries of brachiocephalic veins

The brachiocephalic veins receive the following tributaries:

- the *vertebral vein*, **vena vertebralis** accompanies the vertebral artery (both run through the transverse foramina of the cervical vertebrae). The vein passes the foramen transversarium of the C7 and proceeds

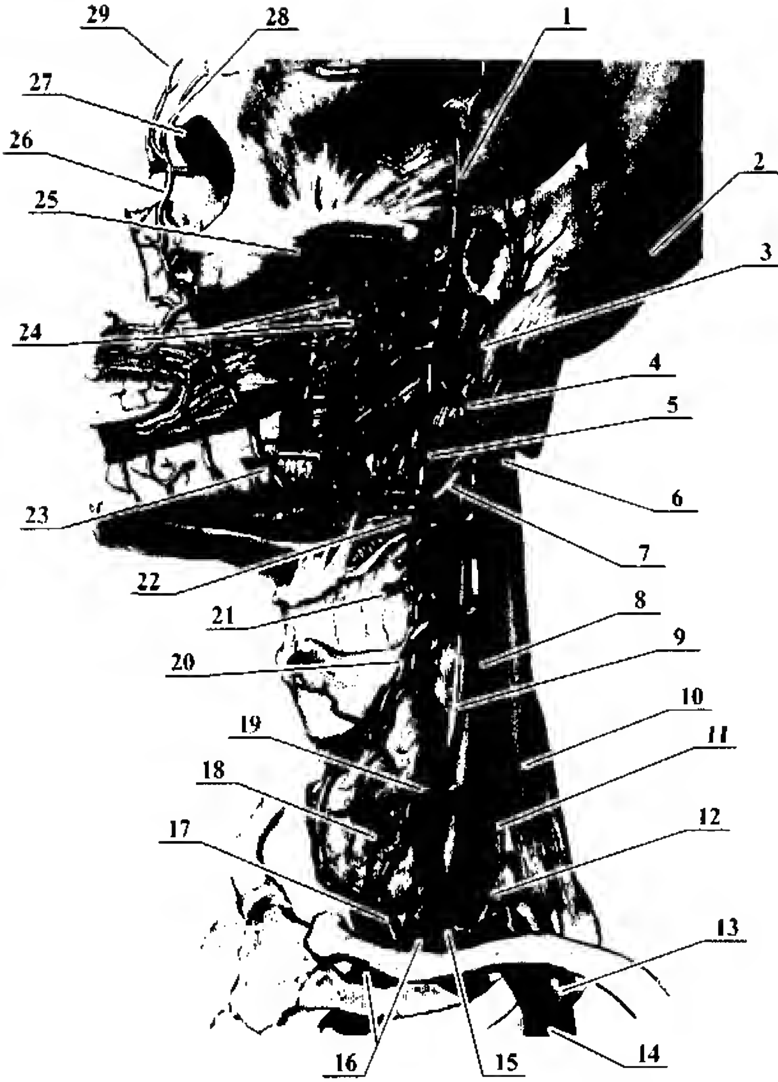


Fig. 108. The veins of head and neck, right aspect. 1 — v. temporalis superficialis; 2, 6 — v. occipitalis; 3 — v. auricularis posterior; 4, 12 — v. jugularis externa; 5 — v. retromandibularis; 7 — n. hypoglossus; 8 — v. jugularis interna; 9 — n. vagus; 10 — m. scalenus medius; 11 — m. scalenus anterior; 13 — a. subclavia; 14 — v. subclavia; 15 — v. jugularis anterior; 16 — v. brachocephalica sinistra; 17 — vv. thyroideae inferiores; 18 — glandula thyroidea; 19 — v. thyroidea media; 20 — v. thyroidea superior; 21 — v. laryngea superior; 22 — v. lingualis; 23 — v. facialis; 24 — plexus pterygoideus; 25 — v. infraorbitalis; 26 — v. angularis; 27 — v. nasofrontalis; 28 — v. supraorbitalis; 29 — v. supratrochlearis.

to the related collector. The vein drains the vertebral plexuses and the occipital region;

- the *inferior thyroid vein*, **vena thyroidea inferior** drains the *unpaired thyroid plexus*. The plexus receives the *thymic veins*, the *inferior laryngeal veins*, the *tracheal veins*, the *oesophageal veins* etc;
- the *internal thoracic veins*, **venae thoracicae internae**, paired, accompany each artery of the same name. They drain the abdominal walls (the *superior epigastric veins*, **venae epigastricae superiores**), the diaphragm (the *musculophrenic veins*, **venae musculophrenicae**) and the intercostal spaces (the *anterior intercostal veins*, **venae intercostales anteriores**). The superior epigastric veins anastomose with the inferior epigastric and the para-umbilical veins participating thus in formation of the cava-caval and portocaval anastomoses.

Apart from the veins mentioned, the brachiocephalic veins drain the veins of thymus, pericardium, mediastinum, bronchi, trachea and esophagus.

THE INTERNAL JUGULAR VEIN, VENA JUGULARIS INTERNA

Relations of the internal jugular vein

The internal jugular vein arises directly from the sigmoid sinus. The dilated segment situated within the jugular foramen is the *superior bulb of jugular vein*, **bulbus superior venae jugularis**. Within the cervical region, the vein initially runs posterior to the internal carotid artery and then laterally from the common carotid artery (Fig. 108). The latter artery, the vagus nerve and the vein constitute the principal cervical neurovascular bundle. The inferior portion of the vein is also dilated — this is the *inferior bulb of jugular vein*, **bulbus inferior venae jugularis**. This area houses one or two valves.

The tributaries of the internal jugular vein

The internal jugular vein drains the entire head and neck and thus features the intracranial and the extracranial tributaries.

The intracranial tributaries of the internal jugular vein

The *dural venous sinuses*, sinus **durae matris**

Difference between the sinuses and veins

The dural venous sinuses are the venous canals formed of dura mater. Internal surface of the canals features endothelial investment. Unlike the veins, the sinuses are formed of dense fibrous tissue and lack muscular fibers. They are fixed to the cranial bones at the related grooves and have no valves. The lumen of a typical sinus is of triangular shape. The sinuses never collapse and always maintain the original shape (which is a surgical concern). The sinuses distinguished are like the following (Fig. 28, 29, 109):

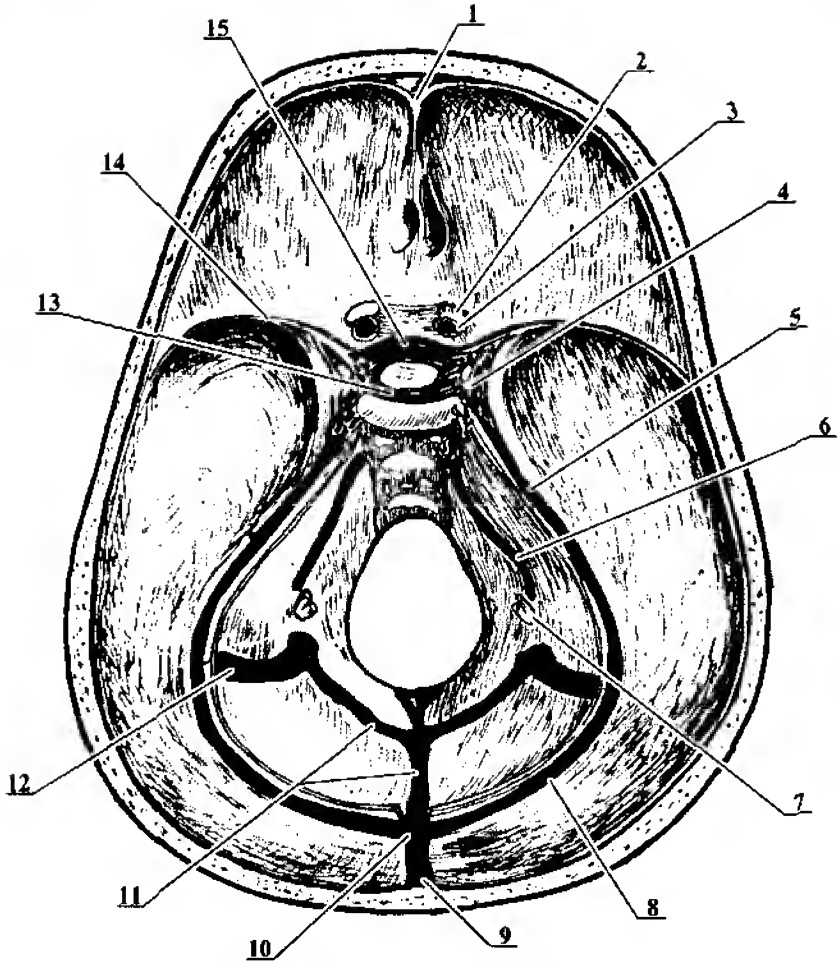


Fig. 109. The dural venous sinuses. 1 — crista gali; 2 — n. opticus; 3 — a. ophthalmica; 4 — sinus cavernosus; 5 — sinus petrosus superior; 6 — sinus petrosus inferior; 7 — nn. vagus et glossopharyngeus; 8 — sinus transversus; 9 — sinus sagittalis superior; 10 — confluens sinuum; 11 — sinus occipitalis; 12 — sinus sigmoideus; 13 — sinus intercavernosus posterior; 14 — sinus sphenoparietalis; 15 — sinus intercavernosus anterior.

- the *transverse sinus*, **sinus trnsversus** occupies the groove for transverse sinus of the occipital bone. It descends laterally to become continuous with the sigmoid sinus;
- the *sigmoid sinus*, **sinus sigmoideus**, paired, is an S-shaped sinus that runs along the respective groove (and it is related to junction of the occipital, temporal and

parietal bones). The sinus reaches the jugular foramen and becomes continuous with the internal jugular vein;

- the *superior sagittal sinus*, **sinus sagittalis superior** the unpaired sinus that occupies the grove for superior sagittal sinus. It runs from anterior to posterior along the upper border of the cerebral falx. Within the posterior cranial fossa, the sinus joins the transverse sinus on any side. The dilated junction area formed of three sinuses is the *confluence of sinuses*, **confluens sinuum**. At the frontal and parietal bones, the sinus has small extensions called the *lateral lacunae*, **lacunae laterales**;
- the *inferior sagittal sinus*, **sinus sagittalis inferior** is an unpaired narrow canal that runs along the inferior border of the cerebral falx. The sinus opens into the straight sinus;
- the *straight sinus*, **sinus rectus** runs along the junction of the cerebral falx and the tentorium cerebelli. It opens into the confluence of sinuses;
- the *occipital sinus*, **sinus occipitlis** rises from the confluence and proceeds along the internal occipital crest. On reaching the foramen magnum, the sinus forks and then runs along the borders of foramen. The sinus is continuous with the sigmoid sinus;
- the *sphenoparietal sinus*, **sinus sphenoparietalis** runs along the posterior border of the lesser wing of sphenoid. It opens into the anterior portion of the cavernous sinus;
- the *cavernous sinus*, **sinus cavernosus** resides on both lateral sides of the body of sphenoid. Its cavity contains numerous endothelium-lined cells separated by the septa. The sinuses communicate via the *anterior* and *posterior intercavernous sinuses*, **sinus intercavernosus anterior et posterior**. Posteriorly, the cavernous sinus opens into the superior and inferior petrosal sinuses. The cavity of the sinus passes the internal carotid artery and the abducent nerve. its lateral wall passes the ophthalmic, oculomotor and trochlear nerves;
- the *superior* and *inferior petrosal sinuses*, **sinus petrosus superior et inferior** occupy the respective grooves of the temporal bone. They communicate the cavernous sinus with the sigmoid sinus;
- the *basilar plexus*, **plexus basilaris** occupies the clivus. It communicates with the cavernous and cavernous sinuses and with the vertebral venous plexuses.

The cerebral veins, venae encephali

The cerebral veins collect venous blood from the brain. They are subdivided into the superficial and deep veins.

The *superficial cerebral veins*, **venae cerebri superficiales** form numerous anastomoses on all surfaces of brain. The following superficial veins are distinguishable:

- the *superior cerebral veins*, **venae superiores cerebri**, numerous (10-15 on each side), they drain the dorsal and medial surfaces of each hemisphere. These veins open into the superior sagittal sinus. The superior cerebral veins are represented with the frontal, parietal and occipital veins;
- the *superficial middle cerebral vein*, **vena media superficialis cerebri** occupies the lateral sulcus. The vein opens into the cavernous sinus;
- the *inferior cerebral veins*, **venae inferiores cerebri** drain the lateral and inferior surfaces of each hemisphere. They run posteriorly and open into the transverse sinus.

The *deep cerebral veins*, **venae profundae cerebri** drain the internal compartments of brain. They merge into two *internal cerebral veins*, **venae internae cerebri** that drain the basal nuclei, white matter, hippocampus, thalamus and the choroid plexuses. The internal veins reside within the roof of the third ventricle. They merge into one *great cerebral vein*, **vena magna cerebri**[1] that opens into the straight sinus.

The veins of brainstem open into the great cerebral vein. The superior veins of cerebellar hemisphere are continuous wit both great cerebral vein and the straight sinus. The inferior veins of cerebellar hemisphere open into the sinuses of cranial base.

The ophthalmic veins, venae ophthalmicae

The ophthalmic veins drain the constituents of the orbit. The *superior ophthalmic vein*, **vena ophthalmica superior** runs above the eyeball. It drains the frontal area, the superior eyelid, the nasal cavity, the lacrimal gland, the related portion of the eyeball and neighboring muscles. At the medial angle of eye, the vein anastomoses with the angular vein (the beginning of the facial vein). The superior ophthalmic vein quits the orbit via the superior orbital fissure and opens into the cavernous sinus. The *inferior ophthalmic vein*, **vena ophthalmica inferior** runs along the inferior wall of the orbit. It drains the inferior eyelid, the inferior portion of the eyeball and neighboring muscles.

Clinical application

Anastomosis between the facial and orbital veins is of a certain clinical significance. The valveless angular vein may carry the pathogens or even the emboli to the superior ophthalmic vein from where they may appear within the cavernous sinus (i.e. within the cranial cavity). This may result in severe complications.

The diploic veins, venae diploicae

The diploic veins are the thin-walled veins embedded into the cancellous bone of calvaria. Depending

[1] the Galen's vein

on location, the following diploic veins are distinguished:

- the *frontal diploic vein*, **vena diploica frontalis**;
- the *anterior* and *posterior temporal diploic veins*, **venae diploicae temporales (anterior et posterior)**;
- the *occipital diploic vein*, **vena diploica occipitalis**;

The diploic veins open into both dural venous sinuses and the extrinsic veins of head.

The emissary veins, venae emissariae[1]

The emissary veins communicate the dural venous sinuses with the extrinsic veins of head. They pass within the respective cranial canals. The largest emissary veins are:

- the *parietal emissary vein*, **vena emissaria parietalis** passes within the *parietal foramen*. It communicates the superior sagittal sinus with the superficial temporal vein;
- the *mastoid emissary vein*, **vena emissaria mastoidea** passes within the mastoid foramen. It communicates the transverse sinus with the occipital vein;
- the *condylar emissary vein*, **vena emissaria condylaris** passes within the condylar canal. It communicates the sigmoid sinus with the external vertebral plexus;
- the *occipital emissary vein*, **vena emissaria occipitalis**;

Small venous plexuses situated within the hypoglossal canal, the foramen ovale and the carotid canal also belong to the emissary veins.

The extracranial tributaries of the internal jugular vein

The internal jugular vein has numerous tributaries within the cervical region. The greatest related vessels are the facial, retromandibular, superior thyroid and the pharyngeal veins (Fig. 108).

The *facial vein*, **vena facialis** branches off similarly to the facial artery. It arises at the medial angle of eye (as the *angular vein*, **vena angularis**) and descends to the cervical region. Within the cervical region, the artery declines posteriorly and joins the retromandibular vein. The veins merge into a single trunk, which opens into the internal jugular vein. Sometimes the veins join the jugular vein separately. The facial vein drains the frontal region, the nose, the eyelids, the lips, the soft palate, the parotid gland, the muscles of the oral diaphragm and the submandibular gland. The facial vein anastomoses with the ophthalmic arteries directly and with the pterygoid plexus via the deep facial vein (Fig. 108).

The *retromandibular vein*, **vena retromandibularis** is related to both superficial temporal and maxillary arteries. It arises anterior to the auricle within the parotid gland. It drains the superficial temporal and the maxil-

[1] emissarium (Latin) — the outlet channel

lary veins. Upon reaching the cervical region, the vein joins the internal jugular vein. It features a permanent anastomosis with the external jugular vein. The retromandibular vein is formed of the following veins:

- the *superficial temporal veins*, **venae temporales superficiales**, they drain several areas of head, face, the external ear, the parotid gland and the tympanic cavity;
- the *maxillary veins*, **venae maxillaries** accompany the artery of the same name. They drain the *pterygoid plexus*, **plexus pterygoideus** situated deep around the pterygoid muscles. The plexus in turn drains the masticatory muscles, the dura mater, the upper and lower teeth and the oral and nasal mucosa. The pterygoid plexus anastomoses with the facial vein via the *deep facial vein*, **vena profunda faciei**.

Other tributaries

Apart from the retromandibular and facial veins, the internal jugular vein receives the following smaller veins:

- the *lingual vein*, **vena lingualis** drains the tongue;
- the *superior thyroid vein*, **vena thyroidea superior** drains the thyroid gland, the larynx and the cervical muscles;
- the *pharyngeal veins*, **venae pharyngeae** drain the *pharyngeal plexus*, **plexus pharyngeus**.

THE EXTERNAL JUGULAR VEIN, VENA JUGULARIS EXTERNA

The external jugular vein is a subcutaneous vein that arises by the union of two tributaries – the anterior, which is the anastomosis with the retromandibular vein and the posterior formed of the occipital and posterior auricular veins. The vein crosses the sternocleidomastoid and enters the greater supraclavicular fossa. There it opens into the *venous angle* – the junction point of the subclavian and internal jugular veins. The external jugular vein receives the suprascapular and transverse cervical veins, and the anterior jugular vein.

THE ANTERIOR JUGULAR VEIN, VENA JUGULARIS ANTERIOR

The anterior jugular vein arises from small superficial veins of the sublingual area. The veins descend to the manubrium of sternum and merge to form the *jugular venous arch*, **arcus venosus jugularis**. The lateral ends of the arch open into the external jugular vein before it joins the *venous angle*.

THE SUBCLAVIAN VEIN, VENA SUBCLAVIA

Relations of the subclavian vein

The subclavian vein is a direct continuation of the axillary vein. The veins are delimited by the external border of the first rib. The axillary vein is a great vessel that resides within the cervical region anterior to the *scalenus anterior* and posterior to the clavicle. The vein joins the internal jugular vein to form the brachiocephalic vein. The subclavian vein receives the *pectoral veins*, **venae pectorales** and the *dorsal scapular vein*, **vena scapularis dorsalis**.

Clinical applications

The axillary vein is fixed to periosteum of neighboring bones (i.e. the first rib and clavicle), to the tendon of the anterior scalene and to the cervical fascia. Fixed so, the vein is unable to collapse in case of severance. In this case, the air may appear within the vein lumen (because of negative pressure within the thoracic cavity and pumping action of heart) producing the *venous air embolism*. The state is extremely dangerous because the air may fill the entire right side of heart and stop blood flow through it.

THE AXILLARY VEIN, VENA AXILLARIS

The axillary vein is a direct continuation of the brachial vein. The vein ascends anteromedially from the axillary artery and reaches the first rib to become continuous with the subclavian vein. The tributaries of the axillary vein correspond to the branches of the axillary artery (the *lateral thoracic* and *subscapular veins*, the *anterior* and *posterior circumflex humeral veins* etc.). It also receives the *thoraco-epigastric veins*, **venae thoracoepigastricae** that drain the thoracic and abdominal walls. The thoraco-epigastric veins anastomose with the *superficial epigastric veins* related to the femoral vein. These veins form the cava-caval anastomosis.

THE VEINS OF UPPER LIMBS

The veins of upper limb are subdivided into the superficial and deep. The superficial veins are embedded into the subcutaneous fat. The paired deep veins accompany the respective arteries (the *venae comitantes*).

The **superficial veins** arise at the dorsal surface of hand with the *dorsal venous network of hand*, **rete venosum dorsal manus** that drains the fingers. The venous network gives rise to the principal superficial veins of upper limb – the cephalic and basilic veins (Fig. 110):

- the *cephalic vein*, **vena cephalica** arises at the dorsal aspect of thumb. The vein runs along the radial aspect of forearm (here it is called the *cephalic vein of forearm*, **vena cephalica antebrachii**), passes the *lateral bicipital* and *deltoideopectoral grooves* and reaches the *clavipectoral triangle*. There it penetrates the clavipectoral fascia and joins the axillary vein;
- the *basilic vein*, **vena basilica** arises from the ulnar portion of the venous network and ascends along the anterior surface of the forearm on the same side (the *basilic vein of forearm*, **vena basilica antebrachii**). Then the vein crosses the cubital fossa and enters the *medial bicipital groove*. At the upper third of the arm, the vein pierces the brachial fascia and joins one of the brachial veins. Very often, the basilic vein appears to be larger than the brachial vein because it is continuous with the axillary vein;
- the *median cubital vein*, **vena mediana cubiti** is a short but important anastomosis between the cephalic and basilic veins that crosses the cubital fossa. The vein maintains communication with the deep veins of the cubital fossa. Shape

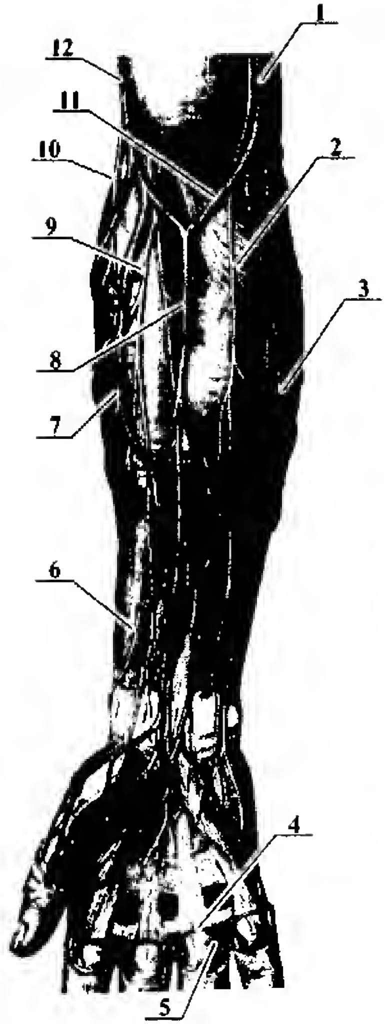


Fig. 110. The superficial veins and nerves of the right upper limb, anterior view. 1 – v. basilica; 2 – n. cutaneus antebrachii medialis; 3 – v. basilica antebrachii; 4 – arcus venosus palmaris superficialis; 5 – vv. digitales palmares; 6 – r. palmaris n. radialis; 7 – v. cephalica antebrachii; 8 – mediana antebrachii; 9 – n. cutaneus antebrachii lateralis (n. musculocutaneus); 10 – n. cutaneus antebrachii posterior (n. radialis); 11 – v. mediana cubiti; 12 – v. cephalica.

and position of the vein vary from individual to individual. This vein is of clinical significance because it is used for IV injections.

The **deep veins**, usually paired, accompany the respective arteries. The upper limb thus features double superficial and deep palmar arches, double *ulnar veins*, **venae ulnares**, double *radial veins*, **venae radiales** etc.

Two *brachial veins*, **venae brachiales** merge into a single vein in the upper third of the arm. The latter vein joins the *basilic vein*, which becomes continuous with the axillary veins. The deep veins anastomose with each other and with the superficial veins. Both superficial and deep veins have numerous valves.

THE AZYGOS VEIN, VENA AZYGOS

Relations of the azygos vein

The azygos vein arises within the abdominal cavity as the longitudinal anastomosis that associates the right lumbar veins — the *right ascending lumbar vein*, **vena lumbalis ascendens dextra**. The latter vein reaches the thoracic cavity via the opening in the diaphragm. Within the thoracic cavity, the vein resides on the right side of the vertebral column, posterior to the esophagus, and to the right of the thoracic duct and aorta (Fig. 111). At the level of the Th4, the vein rounds the right main bronchus (this is the *arch of azygos vein*, **arcus venae azygos**) and joins the SVC outside its pericardial enfolding. The vein accepts the visceral and the parietal tributaries.

The parietal tributaries

The parietal tributaries of the azygos vein are like the following:

- the *posterior intercostal veins*, **venae intercostales posteriores** (nine right lower veins) accompany the respective arteries within the costal grooves. They drain the vertebral plexuses and the thoracic walls;
- the *right superior intercostal vein*, **vena intercostalis superior dextra** is the common trunk formed of three upper right posterior intercostal veins;
- the *superior phrenic veins*, **vena phrenicae superiores** drain the diaphragm.

The **visceral tributaries** are the *oesophageal veins*, **venae oesophageales**, the *bronchial veins*, **venae bronchiales**, the *pericardial veins*, **venae pericardiacae** and the *mediastinal veins*, **venae mediastinales**. The oesophageal veins anastomose with the gastric veins that carry blood to the hepatic portal vein.

THE HEMI-AZYGOS VEIN, VENA HEMIAZYGOS

The hemi-azygos vein arises similarly to the azygos vein i.e. with the *left ascending lumbar vein*, **vena lumbalis ascendens sinistra**.

Within the thoracic cavity, the vein runs along the left side of the vertebral column, posterior to the aorta. The vein receives 4-5 left lower *posterior intercostal veins*, **venae intercostales posteriores**. At the level of Th7 or Th8, the hemi-azygos vein declines

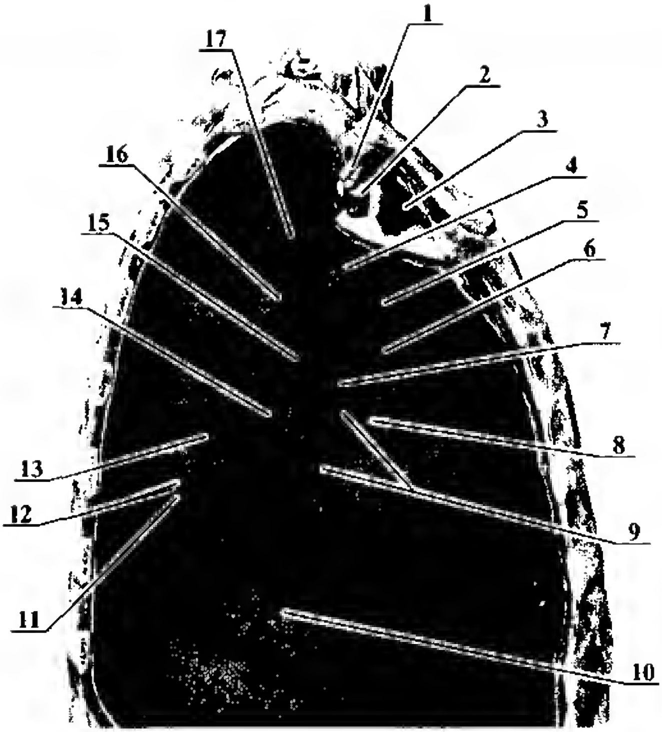


Fig. 111. The parietal veins of thoracic cavity, right side. 1 — plexus brachialis; 2 — a. subclavia; 3 — v. sublavia; 4 — n. vagus; 5 — n. phrenicus; 6 — v. pericardiacophrenica; 7 — a. pulmonalis; 8 — v. cava superior; 9 — vv. pulmonales; 10 — m. phrenicus; 11 — n. intercostalis; 12 — a. et v. intercostalis posterior; 13 — truncus sympathicus; 14 — v. azygos; 15 — bronchus principalis; 16 — v. intercostalis superior dextra; 17 — oesophagus.

rightwards, crosses the vertebral column and joins the azygos vein. The left upper posterior intercostal veins merge to form the *accessory hemi-azygos vein*, **vena hemiazygos accessoria**, which joins the hemi-azygos vein.

Anastomoses related to the azygos and hemi-azygos veins

Both veins arise from the lumbar veins, which are the tributaries of the inferior vena cava. As far as they open into the superior vena cava, they form a large cava-caval anastomosis.

The veins of vertebral column

The veins of vertebral column form the plexuses situated all along the vertebral column. Depending on location, the external and internal venous vertebral plexuses are distinguishable:

- the *anterior* and *posterior internal vertebral plexuses*, **plexus venosus**

vertebralis internus (anterior et posterior) reside within the epidural space of the vertebral canal. They arise from the vertebral veins, the spinal veins and the meningeal veins;

- the *anterior* and *posterior external vertebral plexuses*, **plexus venosus vertebralis externus (anterior et posterior)** reside outside the vertebral canal. The plexuses communicate via the *basivertebral veins*, **venae basivertebrales** embedded into the cancellous bone of the vertebrae.

The vertebral plexuses drain blood to the *intervertebral veins*, **venae intervertebrales** and further to the *vertebral veins* (in the cervical region), *posterior intercostal veins* (in the thoracic region), *lumbar veins* (in the lumbar region) and the *sacral veins* (the sacral region). The plexuses associate the systems of the superior and inferior venae cavae forming thus a large cava-caval anastomosis.

THE INFERIOR VENA CAVA, VENA CAVA INFERIOR

Relations of the inferior vena cava

The inferior vena cava is the greatest systemic vein (2.5-3 cm wide). It arises at L5 by the union of the common iliac veins (Fig. 112). The junction point resides below and to the right of the aortic bifurcation, and posterior to the right common iliac artery. The IVC ascends on the right sides of the bodies of the L3–L5 vertebrae and on the right psoas major to the right of the aorta. The upper portion of IVC occupies the *groove for vena cava* on the visceral surface of liver. The IVC leaves the abdominal cavity via the *caval opening* in the central tendon of the diaphragm and enters the thoracic cavity at the level of Th8. Upon reaching the heart, the IVC traverses the pericardium and enters the right atrium. The IVC is 17-20 cm long; the thoracic portion is 2-3 cm long. The vein receives parietal and visceral tributaries.

The visceral tributaries

The greatest visceral tributaries of the IVC are the hepatic and the renal veins. The IVC also receives the veins from the gonads and suprarenal glands.

- the *hepatic veins*, **venae hepaticae** drain the entire liver. They open into the IVC segment related to the groove for vena cava. The hepatic veins distinguishable are three larger veins (the superior, intermediate and inferior) and some smaller ones. All veins are fully incorporated into the liver parenchyme and one can see their openings after dissecting the posterior wall of the vein;

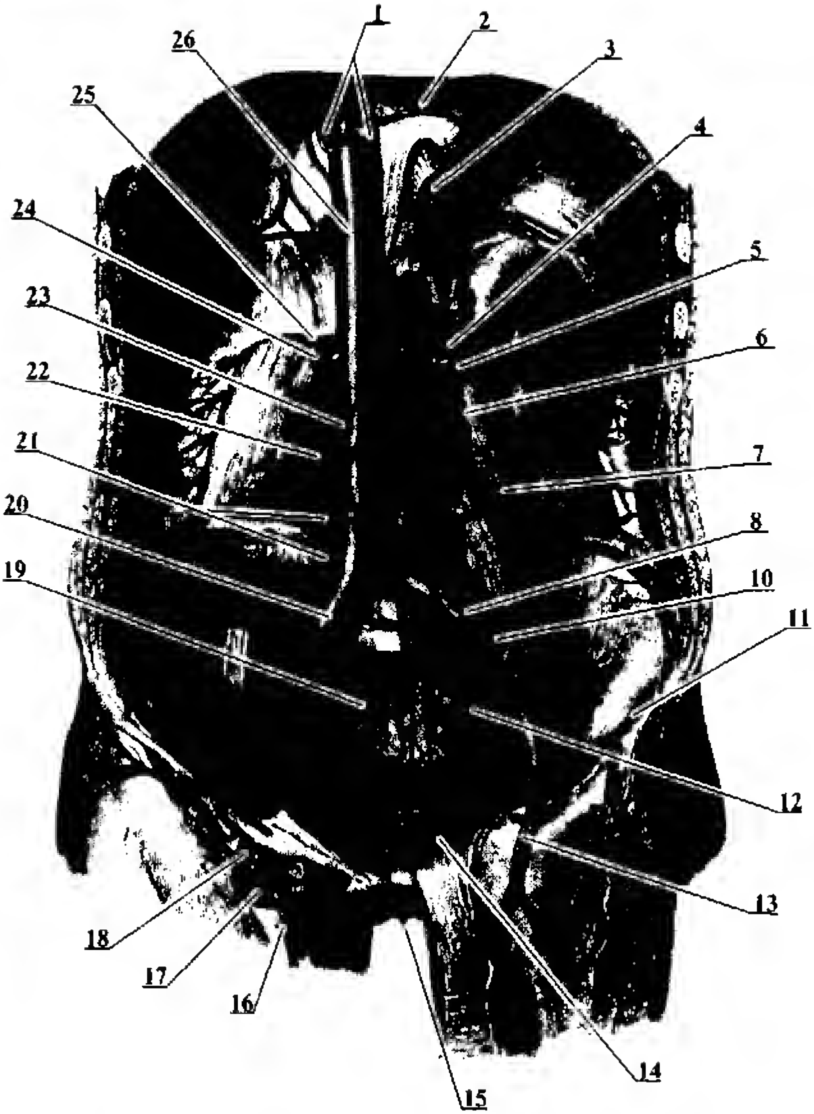


Fig. 112. The inferior vena cava. 1 — vv. hepaticae; 2 - vv. phrenicae inferiores; 3 — oesophagus; 4 — v. suprarenalis sinistra; 5 — v. renalis sinistra; 6 — v. ovarica sinistra; 7 — ureter; 8 — v. iliaca communis; 9 — v. glutea superior; 10 - v. iliaca externa; 11 — v. circumflexa ilium superficialis; 12 — v. pudenda interna; 13 - v. epigastrica inferior; 14 plexus venosus uterinus et vaginalis; 15 — v. dorsalis profunda clitoridis; 16 — v. saphena magna; 17 — v. femoralis; 18 — v. epigastrica superficialis; 19 — v. sacralis mediana; 20 — v. iliaca interna; 21 - vv. lumbales; 22 — vv. lumbales ascendens; 23 — v. ovarica dextra; 24 — v. renalis dextra; 25 — v. suprarenalis dextra; 26 — v. cava inferior.

thus features anastomoses related to both vertical and horizontal planes.

Clinical applications

The arteries of lower limb are often affected by atherosclerosis and obliterating endarteritis, which feature pathological growth of connective tissue in the inner layer and lipid infiltration of vascular wall. The pathologies result in occlusion of the vessel affected. Collateral circulation may compensate slow progressing occlusion of the distal arteries yet occlusion of min trunks results in severe ischemia and even gangrene. Gangrene requires amputation of the limb. Treatment of the state nowadays includes various reconstructive and plastic surgeries.

THE VEINS OF SYSTEMIC CIRCULATORY ROUTE

The systemic circulatory route comprises three venous systems:

1) the superior vena cava (SVC) system;

2) the inferior vena cava system;

3) the coronary sinus system (the veins of heart).

The SVC system features a specific hepatic portal vein system that carries blood to the liver.

THE SUPERIOR VENA CAVA, VENA CAVA SUPERIOR

Relations of the superior vena cava

The superior vena cava arises from merging left and right *brachiocephalic veins*, **venae brachiocephalicae** posterior to the right first sternocostal joint. The brachiocephalic veins drain the head, the neck and the upper limbs (Fig. 108).

The SVC descends to enter the right atrium at the level of right third intercostal space; the vein is 5-6 cm long and 2.5 cm wide. On the left one can distinguish the ascending aorta and on the right – the mediastinal pleura and phrenic nerve. The right pulmonary vein resides posterior to the SVC and the thymus and right lung – anterior to it. The lower portion of the vein is enfolded into the serous pericardium. The VSC receives the azygos vein that rounds the root of right lung and passes from superior to inferior and from posterior to anterior.

THE BRACHIOCEPHALIC VEIN, VENA BRACHIOCEPHALICA

Relations of the brachiocephalic vein

Each brachiocephalic vein is formed of the internal jugular and the subclavian veins. The junction point is situated posterior to the respective sternoclavicular joint. The right vein is shorter than the right (2-3 cm); it runs vertically down. The left vein is about twice as longer (4-5 cm); it slants down and rightwards to join the right vein.

The tributaries of brachiocephalic veins

The brachiocephalic veins receive the following tributaries:

- the *vertebral vein*, **vena vertebralis** accompanies the vertebral artery (both run through the transverse foramina of the cervical vertebrae). The vein passes the foramen transversarium of the C7 and proceeds

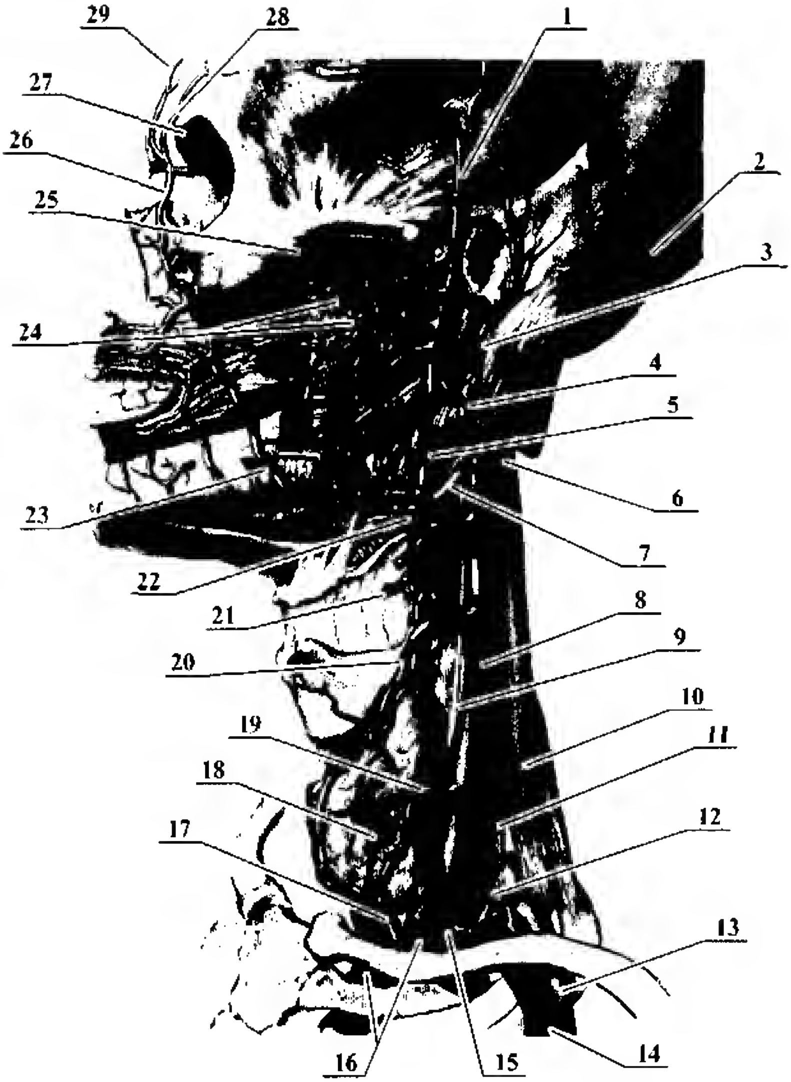


Fig. 108. The veins of head and neck, right aspect. 1 — v. temporalis superficialis; 2, 6 — v. occipitalis; 3 — v. auricularis posterior; 4, 12 — v. jugularis externa; 5 — v. retromandibularis; 7 — n. hypoglossus; 8 — v. jugularis interna; 9 — n. vagus; 10 — m. scalenus medius; 11 — m. scalenus anterior; 13 — a. subclavia; 14 — v. subclavia; 15 — v. jugularis anterior; 16 — v. brachiocephalica sinistra; 17 — vv. thyroideae inferiores; 18 — glandula thyroidea; 19 — v. thyroidea media; 20 — v. thyroidea superior; 21 — v. laryngea superior; 22 — v. lingualis; 23 — v. facialis; 24 — plexus pterygoideus; 25 — v. infraorbitalis; 26 — v. angularis; 27 — v. nasofrontalis; 28 — v. supraorbitalis; 29 — v. supratrochlearis.

to the related collector. The vein drains the vertebral plexuses and the occipital region;

- the *inferior thyroid vein*, **vena thyroidea inferior** drains the *unpaired thyroid plexus*. The plexus receives the *thymic veins*, the *inferior laryngeal veins*, the *tracheal veins*, the *oesophageal veins* etc;
- the *internal thoracic veins*, **venae thoracicae internae**, paired, accompany each artery of the same name. They drain the abdominal walls (the *superior epigastric veins*, **venae epigastricae superiores**), the diaphragm (the *musculophrenic veins*, **venae musculophrenicae**) and the intercostal spaces (the *anterior intercostal veins*, **venae intercostales anteriores**). The superior epigastric veins anastomose with the inferior epigastric and the para-umbilical veins participating thus in formation of the cava-caval and portocaval anastomoses.

Apart from the veins mentioned, the brachiocephalic veins drain the veins of thymus, pericardium, mediastinum, bronchi, trachea and esophagus.

THE INTERNAL JUGULAR VEIN, VENA JUGULARIS INTERNA

Relations of the internal jugular vein

The internal jugular vein arises directly from the sigmoid sinus. The dilated segment situated within the jugular foramen is the *superior bulb of jugular vein*, **bulbus superior venae jugularis**. Within the cervical region, the vein initially runs posterior to the internal carotid artery and then laterally from the common carotid artery (Fig. 108). The latter artery, the vagus nerve and the vein constitute the principal cervical neurovascular bundle. The inferior portion of the vein is also dilated — this is the *inferior bulb of jugular vein*, **bulbus inferior venae jugularis**. This area houses one or two valves.

The tributaries of the internal jugular vein

The internal jugular vein drains the entire head and neck and thus features the intracranial and the extracranial tributaries.

The intracranial tributaries of the internal jugular vein

The *dural venous sinuses*, sinus **durae matris**

Difference between the sinuses and veins

The dural venous sinuses are the venous canals formed of dura mater. Internal surface of the canals features endothelial investment. Unlike the veins, the sinuses are formed of dense fibrous tissue and lack muscular fibers. They are fixed to the cranial bones at the related grooves and have no valves. The lumen of a typical sinus is of triangular shape. The sinuses never collapse and always maintain the original shape (which is a surgical concern). The sinuses distinguished are like the following (Fig. 28, 29, 109):

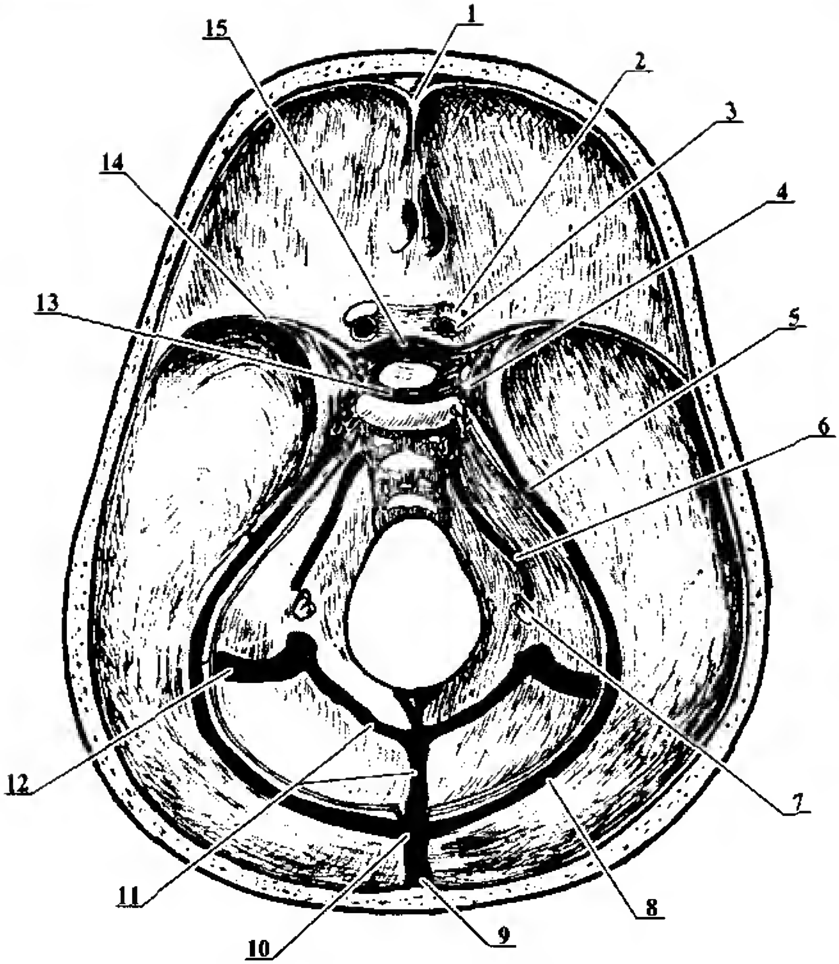


Fig. 109. The dural venous sinuses. 1 — crista gali; 2 — n. opticus; 3 — a. ophthalmica; 4 — sinus cavernosus; 5 — sinus petrosus superior; 6 — sinus petrosus inferior; 7 — nn. vagus et glossopharyngeus; 8 — sinus transversus; 9 — sinus sagittalis superior; 10 — confluens sinuum; 11 — sinus occipitalis; 12 — sinus sigmoideus; 13 — sinus intercavernosus posterior; 14 — sinus sphenoparietalis; 15 — sinus intercavernosus anterior.

- the *transverse sinus,* **sinus trnsversus** occupies the groove for transverse sinus of the occipital bone. It descends laterally to become continuous with the sigmoid sinus;
- the *sigmoid sinus,* **sinus sigmoideus**, paired, is an S-shaped sinus that runs along the respective groove (and it is related to junction of the occipital, temporal and

parietal bones). The sinus reaches the jugular foramen and becomes continuous with the internal jugular vein;

- the *superior sagittal sinus*, **sinus sagittalis superior** the unpaired sinus that occupies the grove for superior sagittal sinus. It runs from anterior to posterior along the upper border of the cerebral falx. Within the posterior cranial fossa, the sinus joins the transverse sinus on any side. The dilated junction area formed of three sinuses is the *confluence of sinuses*, **confluens sinuum**. At the frontal and parietal bones, the sinus has small extensions called the *lateral lacunae*, **lacunae laterales**;
- the *inferior sagittal sinus*, **sinus sagittalis inferior** is an unpaired narrow canal that runs along the inferior border of the cerebral falx. The sinus opens into the straight sinus;
- the *straight sinus*, **sinus rectus** runs along the junction of the cerebral falx and the tentorium cerebelli. It opens into the confluence of sinuses;
- the *occipital sinus*, **sinus occipitlis** rises from the confluence and proceeds along the internal occipital crest. On reaching the foramen magnum, the sinus forks and then runs along the borders of foramen. The sinus is continuous with the sigmoid sinus;
- the *sphenoparietal sinus*, **sinus sphenoparietalis** runs along the posterior border of the lesser wing of sphenoid. It opens into the anterior portion of the cavernous sinus;
- the *cavernous sinus*, **sinus cavernosus** resides on both lateral sides of the body of sphenoid. Its cavity contains numerous endothelium-lined cells separated by the septa. The sinuses communicate via the *anterior* and *posterior intercavernous sinuses*, **sinus intercavernosus anterior et posterior**. Posteriorly, the cavernous sinus opens into the superior and inferior petrosal sinuses. The cavity of the sinus passes the internal carotid artery and the abducent nerve. its lateral wall passes the ophthalmic, oculomotor and trochlear nerves;
- the *superior* and *inferior petrosal sinuses*, **sinus petrosus superior et inferior** occupy the respective grooves of the temporal bone. They communicate the cavernous sinus with the sigmoid sinus;
- the *basilar plexus*, **plexus basilaris** occupies the clivus. It communicates with the cavernous and cavernous sinuses and with the vertebral venous plexuses.

The cerebral veins, venae encephali

The cerebral veins collect venous blood from the brain. They are subdivided into the superficial and deep veins.

The *superficial cerebral veins*, **venae cerebri superficiales** form numerous anastomoses on all surfaces of brain. The following superficial veins are distinguishable:

- the *superior cerebral veins*, **venae superiores cerebri**, numerous (10-15 on each side), they drain the dorsal and medial surfaces of each hemisphere. These veins open into the superior sagittal sinus. The superior cerebral veins are represented with the frontal, parietal and occipital veins;
- the *superficial middle cerebral vein*, **vena media superficialis cerebri** occupies the lateral sulcus. The vein opens into the cavernous sinus;
- the *inferior cerebral veins*, **venae inferiores cerebri** drain the lateral and inferior surfaces of each hemisphere. They run posteriorly and open into the transverse sinus.

The *deep cerebral veins*, **venae profundae cerebri** drain the internal compartments of brain. They merge into two *internal cerebral veins*, **venae internae cerebri** that drain the basal nuclei, white matter, hippocampus, thalamus and the choroid plexuses. The internal veins reside within the roof of the third ventricle. They merge into one *great cerebral vein*, **vena magna cerebri**[1] that opens into the straight sinus.

The veins of brainstem open into the great cerebral vein. The superior veins of cerebellar hemisphere are continuous wit both great cerebral vein and the straight sinus. The inferior veins of cerebellar hemisphere open into the sinuses of cranial base.

The ophthalmic veins, venae ophthalmicae

The ophthalmic veins drain the constituents of the orbit. The *superior ophthalmic vein*, **vena ophthalmica superior** runs above the eyeball. It drains the frontal area, the superior eyelid, the nasal cavity, the lacrimal gland, the related portion of the eyeball and neighboring muscles. At the medial angle of eye, the vein anastomoses with the angular vein (the beginning of the facial vein). The superior ophthalmic vein quits the orbit via the superior orbital fissure and opens into the cavernous sinus. The *inferior ophthalmic vein*, **vena ophthalmica inferior** runs along the inferior wall of the orbit. It drains the inferior eyelid, the inferior portion of the eyeball and neighboring muscles.

Clinical application

Anastomosis between the facial and orbital veins is of a certain clinical significance. The valveless angular vein may carry the pathogens or even the emboli to the superior ophthalmic vein from where they may appear within the cavernous sinus (i.e. within the cranial cavity). This may result in severe complications.

The diploic veins, venae diploicae

The diploic veins are the thin-walled veins embedded into the cancellous bone of calvaria. Depending

[1] the Galen's vein

on location, the following diploic veins are distinguished:

- the *frontal diploic vein*, **vena diploica frontalis**;
- the *anterior* and *posterior temporal diploic veins*, **venae diploicae temporales (anterior et posterior)**;
- the *occipital diploic vein*, **vena diploica occipitalis**;

The diploic veins open into both dural venous sinuses and the extrinsic veins of head.

The emissary veins, venae emissariae[1]

The emissary veins communicate the dural venous sinuses with the extrinsic veins of head. They pass within the respective cranial canals. The largest emissary veins are:

- the *parietal emissary vein*, **vena emissaria parietalis** passes within the *parietal foramen*. It communicates the superior sagittal sinus with the superficial temporal vein;
- the *mastoid emissary vein*, **vena emissaria mastoidea** passes within the mastoid foramen. It communicates the transverse sinus with the occipital vein;
- the *condylar emissary vein*, **vena emissaria condylaris** passes within the condylar canal. It communicates the sigmoid sinus with the external vertebral plexus;
- the *occipital emissary vein*, **vena emissaria occipitalis**;

Small venous plexuses situated within the hypoglossal canal, the foramen ovale and the carotid canal also belong to the emissary veins.

The extracranial tributaries of the internal jugular vein

The internal jugular vein has numerous tributaries within the cervical region. The greatest related vessels are the facial, retromandibular, superior thyroid and the pharyngeal veins (Fig. 108).

The *facial vein*, **vena facialis** branches off similarly to the facial artery. It arises at the medial angle of eye (as the *angular vein*, **vena angularis**) and descends to the cervical region. Within the cervical region, the artery declines posteriorly and joins the retromandibular vein. The veins merge into a single trunk, which opens into the internal jugular vein. Sometimes the veins join the jugular vein separately. The facial vein drains the frontal region, the nose, the eyelids, the lips, the soft palate, the parotid gland, the muscles of the oral diaphragm and the submandibular gland. The facial vein anastomoses with the ophthalmic arteries directly and with the pterygoid plexus via the deep facial vein (Fig. 108).

The *retromandibular vein*, **vena retromandibularis** is related to both superficial temporal and maxillary arteries. It arises anterior to the auricle within the parotid gland. It drains the superficial temporal and the maxil-

[1] emissarium (Latin) – the outlet channel

lary veins. Upon reaching the cervical region, the vein joins the internal jugular vein. It features a permanent anastomosis with the external jugular vein. The retromandibular vein is formed of the following veins:

- the *superficial temporal veins*, **venae temporales superficiales**, they drain several areas of head, face, the external ear, the parotid gland and the tympanic cavity;
- the *maxillary veins*, **venae maxillaries** accompany the artery of the same name. They drain the *pterygoid plexus*, **plexus pterygoideus** situated deep around the pterygoid muscles. The plexus in turn drains the masticatory muscles, the dura mater, the upper and lower teeth and the oral and nasal mucosa. The pterygoid plexus anastomoses with the facial vein via the *deep facial vein*, **vena profunda faciei**.

Other tributaries

Apart from the retromandibular and facial veins, the internal jugular vein receives the following smaller veins:

- the *lingual vein*, **vena lingualis** drains the tongue;
- the *superior thyroid vein*, **vena thyroidea superior** drains the thyroid gland, the larynx and the cervical muscles;
- the *pharyngeal veins*, **venae pharyngeae** drain the *pharyngeal plexus*, **plexus pharyngeus**.

THE EXTERNAL JUGULAR VEIN, VENA JUGULARIS EXTERNA

The external jugular vein is a subcutaneous vein that arises by the union of two tributaries – the anterior, which is the anastomosis with the retromandibular vein and the posterior formed of the occipital and posterior auricular veins. The vein crosses the sternocleidomastoid and enters the greater supraclavicular fossa. There it opens into the *venous angle* – the junction point of the subclavian and internal jugular veins. The external jugular vein receives the suprascapular and transverse cervical veins, and the anterior jugular vein.

THE ANTERIOR JUGULAR VEIN, VENA JUGULARIS ANTERIOR

The anterior jugular vein arises from small superficial veins of the sublingual area. The veins descend to the manubrium of sternum and merge to form the *jugular venous arch*, **arcus venosus jugularis**. The lateral ends of the arch open into the external jugular vein before it joins the *venous angle*.

THE SUBCLAVIAN VEIN, VENA SUBCLAVIA

Relations of the subclavian vein

The subclavian vein is a direct continuation of the axillary vein. The veins are delimited by the external border of the first rib. The axillary vein is a great vessel that resides within the cervical region anterior to the *scalenus anterior* and posterior to the clavicle. The vein joins the internal jugular vein to form the brachiocephalic vein. The subclavian vein receives the *pectoral veins*, **venae pectorales** and the *dorsal scapular vein*, **vena scapularis dorsalis**.

Clinical applications

The axillary vein is fixed to periosteum of neighboring bones (i.e. the first rib and clavicle), to the tendon of the anterior scalene and to the cervical fascia. Fixed so, the vein is unable to collapse in case of severance. In this case, the air may appear within the vein lumen (because of negative pressure within the thoracic cavity and pumping action of heart) producing the *venous air embolism*. The state is extremely dangerous because the air may fill the entire right side of heart and stop blood flow through it.

THE AXILLARY VEIN, VENA AXILLARIS

The axillary vein is a direct continuation of the brachial vein. The vein ascends anteromedially from the axillary artery and reaches the first rib to become continuous with the subclavian vein. The tributaries of the axillary vein correspond to the branches of the axillary artery (the *lateral thoracic* and *subscapular veins*, the *anterior* and *posterior circumflex humeral veins* etc.). It also receives the *thoraco-epigastric veins*, **venae thoracoepigastricae** that drain the thoracic and abdominal walls. The thoraco-epigastric veins anastomose with the *superficial epigastric veins* related to the femoral vein. These veins form the cava-caval anastomosis.

THE VEINS OF UPPER LIMBS

The veins of upper limb are subdivided into the superficial and deep. The superficial veins are embedded into the subcutaneous fat. The paired deep veins accompany the respective arteries (the *venae comitantes*).

The **superficial veins** arise at the dorsal surface of hand with the *dorsal venous network of hand*, **rete venosum dorsal manus** that drains the fingers. The venous network gives rise to the principal superficial veins of upper limb — the cephalic and basilic veins (Fig. 110):

- the *cephalic vein*, **vena cephalica** arises at the dorsal aspect of thumb. The vein runs along the radial aspect of forearm (here it is called the *cephalic vein of forearm*, **vena cephalica antebrachii**), passes the *lateral bicipital* and *deltoideopectoral grooves* and reaches the *clavipectoral triangle*. There it penetrates the clavipectoral fascia and joins the axillary vein;
- the *basilic vein*, **vena basilica** arises from the ulnar portion of the venous network and ascends along the anterior surface of the forearm on the same side (the *basilic vein of forearm*, **vena basilica antebrachii**). Then the vein crosses the cubital fossa and enters the *medial bicipital groove*. At the upper third of the arm, the vein pierces the brachial fascia and joins one of the brachial veins. Very often, the basilic vein appears to be larger than the brachial vein because it is continuous with the axillary vein;
- the *median cubital vein*, **vena mediana cubiti** is a short but important anastomosis between the cephalic and basilic veins that crosses the cubital fossa. The vein maintains communication with the deep veins of the cubital fossa. Shape

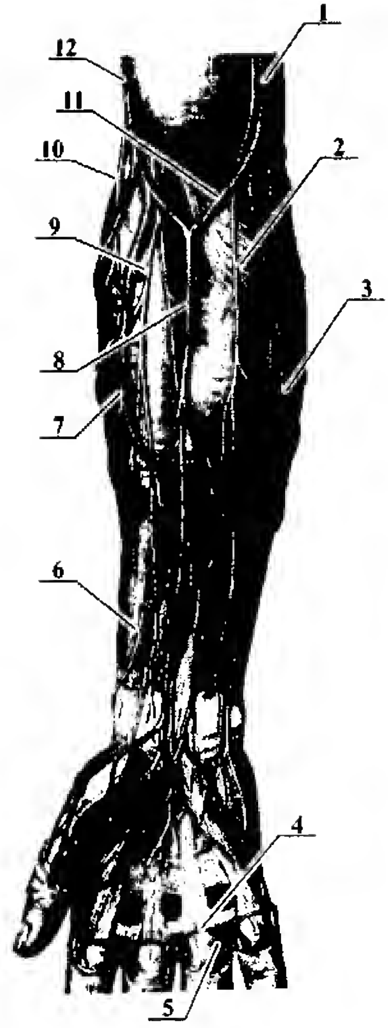


Fig. 110. The superficial veins and nerves of the right upper limb, anterior view.
1 — v. basilica; 2 — n. cutaneus antebrachii medialis; 3 — v. basilica antebrachii; 4 — arcus venosus palmaris superficialis; 5 — vv. digitales palmares; 6 — r. palmaris n. radialis; 7 — v. cephalica antebrachii; 8 — mediana antebrachii; 9 — n. cutaneus antebrachii lateralis (n. musculocutaneus); 10 — n. cutaneus antebrachii posterior (n. radialis); 11 — v. mediana cubiti; 12 — v. cephalica.

and position of the vein vary from individual to individual. This vein is of clinical significance because it is used for IV injections.

The **deep veins**, usually paired, accompany the respective arteries. The upper limb thus features double superficial and deep palmar arches, double *ulnar veins*, **venae ulnares**, double *radial veins*, **venae radiales** etc.

Two *brachial veins*, **venae brachiales** merge into a single vein in the upper third of the arm. The latter vein joins the *basilic vein*, which becomes continuous with the axillary veins. The deep veins anastomose with each other and with the superficial veins. Both superficial and deep veins have numerous valves.

THE AZYGOS VEIN, VENA AZYGOS

Relations of the azygos vein

The azygos vein arises within the abdominal cavity as the longitudinal anastomosis that associates the right lumbar veins — the *right ascending lumbar vein*, **vena lumbalis ascendens dextra**. The latter vein reaches the thoracic cavity via the opening in the diaphragm. Within the thoracic cavity, the vein resides on the right side of the vertebral column, posterior to the esophagus, and to the right of the thoracic duct and aorta (Fig. 111). At the level of the Th4, the vein rounds the right main bronchus (this is the *arch of azygos vein*, **arcus venae azygos**) and joins the SVC outside its pericardial enfolding. The vein accepts the visceral and the parietal tributaries.

The parietal tributaries

The parietal tributaries of the azygos vein are like the following:

- the *posterior intercostal veins*, **venae intercostales posteriores** (nine right lower veins) accompany the respective arteries within the costal grooves. They drain the vertebral plexuses and the thoracic walls;
- the *right superior intercostal vein*, **vena intercostalis superior dextra** is the common trunk formed of three upper right posterior intercostal veins;
- the *superior phrenic veins*, **vena phrenicae superiores** drain the diaphragm.

The **visceral tributaries** are the *oesophageal veins*, **venae oesophageales**, the *bronchial veins*, **venae bronchiales**, the *pericardial veins*, **venae pericardiacae** and the *mediastinal veins*, **venae mediastinales**. The oesophageal veins anastomose with the gastric veins that carry blood to the hepatic portal vein.

THE HEMI-AZYGOS VEIN, VENA HEMIAZYGOS

The hemi-azygos vein arises similarly to the azygos vein i.e. with the *left ascending lumbar vein*, **vena lumbalis ascendens sinistra**.

Within the thoracic cavity, the vein runs along the left side of the vertebral column, posterior to the aorta. The vein receives 4-5 left lower *posterior intercostal veins*, **venae intercostales posteriores**. At the level of Th7 or Th8, the hemi-azygos vein declines

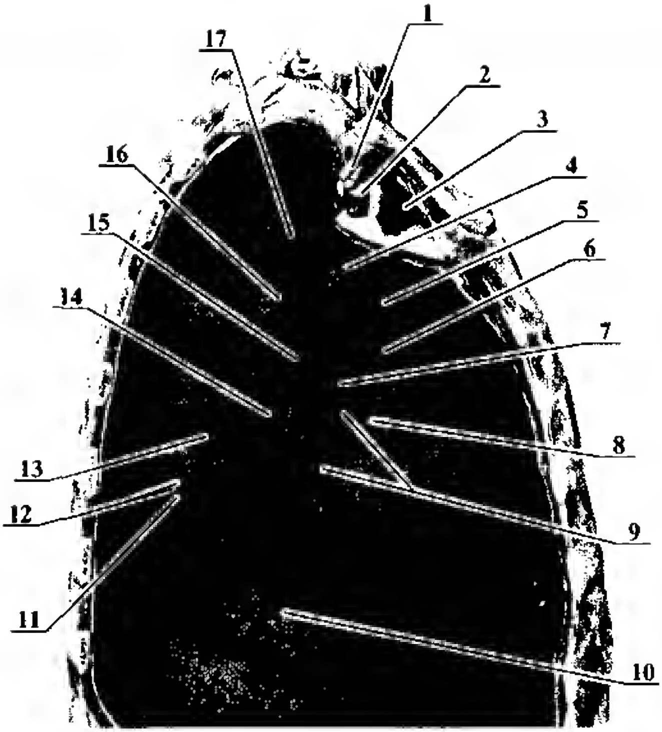


Fig. 111. The parietal veins of thoracic cavity, right side. 1 — plexus brachialis; 2 — a. subclavia; 3 — v. sublavia; 4 — n. vagus; 5 — n. phrenicus; 6 — v. pericardiacophrenica; 7 — a. pulmonalis; 8 — v. cava superior; 9 — vv. pulmonales; 10 — m. phrenicus; 11 — n. intercostalis; 12 — a. et v. intercostalis posterior; 13 — truncus sympathicus; 14 — v. azygos; 15 — bronchus principalis; 16 — v. intercostalis superior dextra; 17 — oesophagus.

rightwards, crosses the vertebral column and joins the azygos vein. The left upper posterior intercostal veins merge to form the *accessory hemi-azygos vein*, **vena hemiazygos accessoria**, which joins the hemi-azygos vein.

Anastomoses related to the azygos and hemi-azygos veins

Both veins arise from the lumbar veins, which are the tributaries of the inferior vena cava. As far as they open into the superior vena cava, they form a large cava-caval anastomosis.

The veins of vertebral column

The veins of vertebral column form the plexuses situated all along the vertebral column. Depending on location, the external and internal venous vertebral plexuses are distinguishable:

- the *anterior* and *posterior internal vertebral plexuses*, **plexus venosus**

vertebralis internus (anterior et posterior) reside within the epidural space of the vertebral canal. They arise from the vertebral veins, the spinal veins and the meningeal veins;

- the *anterior* and *posterior external vertebral plexuses*, **plexus venosus vertebralis externus (anterior et posterior)** reside outside the vertebral canal. The plexuses communicate via the *basivertebral veins*, **venae basivertebrales** embedded into the cancellous bone of the vertebrae.

The vertebral plexuses drain blood to the *intervertebral veins*, **venae intervertebrales** and further to the *vertebral veins* (in the cervical region), *posterior intercostal veins* (in the thoracic region), *lumbar veins* (in the lumbar region) and the *sacral veins* (the sacral region). The plexuses associate the systems of the superior and inferior venae cavae forming thus a large cava-caval anastomosis.

THE INFERIOR VENA CAVA, VENA CAVA INFERIOR

Relations of the inferior vena cava

The inferior vena cava is the greatest systemic vein (2.5-3 cm wide). It arises at L5 by the union of the common iliac veins (Fig. 112). The junction point resides below and to the right of the aortic bifurcation, and posterior to the right common iliac artery. The IVC ascends on the right sides of the bodies of the L3–L5 vertebrae and on the right psoas major to the right of the aorta. The upper portion of IVC occupies the *groove for vena cava* on the visceral surface of liver. The IVC leaves the abdominal cavity via the *caval opening* in the central tendon of the diaphragm and enters the thoracic cavity at the level of Th8. Upon reaching the heart, the IVC traverses the pericardium and enters the right atrium. The IVC is 17-20 cm long; the thoracic portion is 2-3 cm long. The vein receives parietal and visceral tributaries.

The visceral tributaries

The greatest visceral tributaries of the IVC are the hepatic and the renal veins. The IVC also receives the veins from the gonads and suprarenal glands.

- the *hepatic veins*, **venae hepaticae** drain the entire liver. They open into the IVC segment related to the groove for vena cava. The hepatic veins distinguishable are three larger veins (the superior, intermediate and inferior) and some smaller ones. All veins are fully incorporated into the liver parenchyme and one can see their openings after dissecting the posterior wall of the vein;

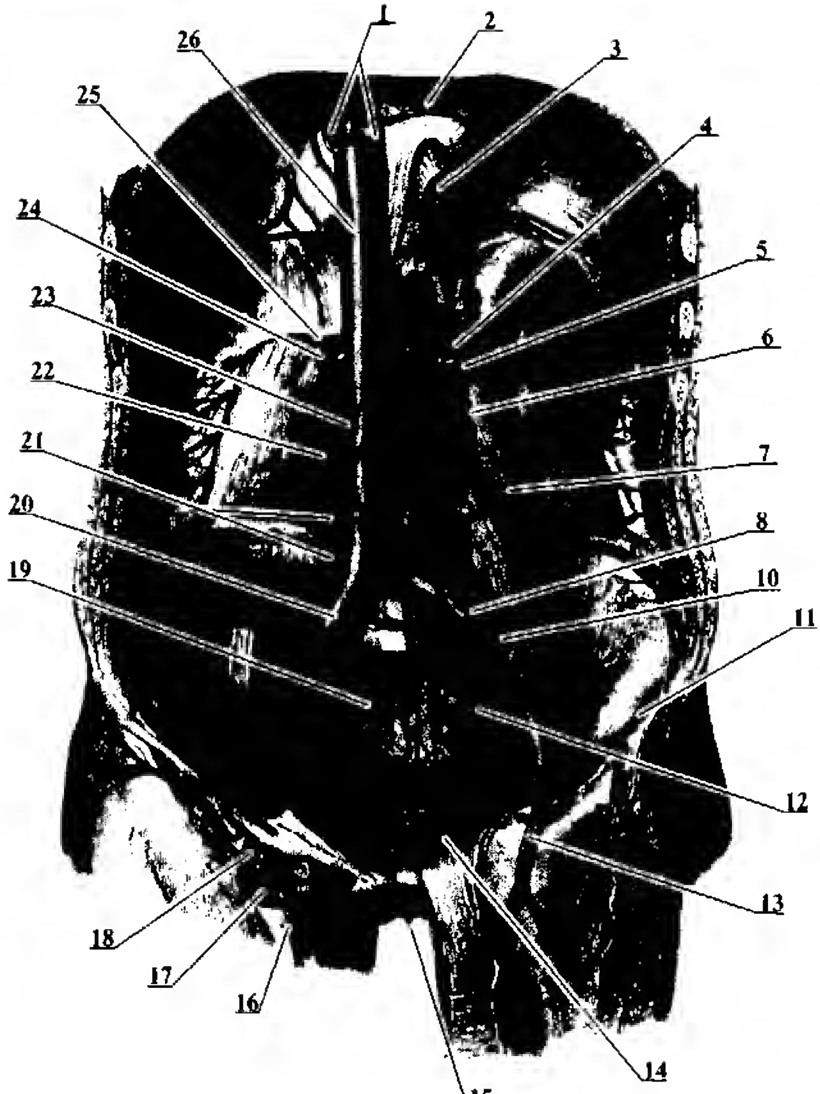


Fig. 112. The inferior vena cava. 1 — vv. hepaticae; 2 - vv. phrenicae inferiores; 3 — oesophagus; 4 — v. suprarenalis sinistra; 5 — v. renalis sinistra; 6 — v. ovarica sinistra; 7 — ureter; 8 — v. iliaca communis; 9 — v. glutea superior; 10 - v. iliaca externa; 11 — v. circumflexa ilium superficialis; 12 — v. pudenda interna; 13 - v. epigastrica inferior; 14 plexus venosus uterinus et vaginalis; 15 — v. dorsalis profunda clitoridis; 16 — v. saphena magna; 17 — v. femoralis; 18 — v. epigastrica superficialis; 19 — v. sacralis mediana; 20 — v. iliaca interna; 21 - vv. lumbales; 22 — vv. lumbales ascendens; 23 — v. ovarica dextra; 24 — v. renalis dextra; 25 — v. suprarenalis dextra; 26 — v. cava inferior.

- the *renal vein*, **vena renalis**, paired, it becomes evident within the hilum of kidney. Both veins run medially to join the IVC. The left renal vein is longer than the right one; it crosses the aorta. The left renal vein receives the left testicular (or ovarian) and the left suprarenal veins;
- the *right testicular ♂ (ovarian ♀) vein*, **vena testicularis ♂ (ovarica ♀) dextra** opens right into the IVC (while the left veins open into the left renal vein). The long veins run along the respective arteries. In males, the testicular vein arises from the *pampiniform plexus*, **plexus pampiniformis** situated within the spermatic cord;
- the *right suprarenal vein*, **vena suprarenalis dextra** opens right into the IVC; the left opens into the left renal artery.

The parietal tributaries

The parietal tributaries of the IVC include the lumbar and inferior phrenic veins:

- the *lumbar veins*, **venae lumbales**, four on each side, they run along the arteries of the same name. The lumbar veins drain the vertebral plexuses and the abdominal walls. The lumbar veins on each side anastomose by means of the *ascending lumbar veins*, **venae lumbales ascendens**, which give rise to the azygos and hemi-azygos veins;
- the *inferior phrenic veins*, **venae phrenicae** accompany the respective arteries.

THE COMMON ILIAC VEIN, VENA ILIACA COMMUNIS

The common iliac vein arises from the union of the external and internal iliac veins at the sacroiliac joint. The right vein resides posterior to the artery of the same name, the left — posterior and medially from the respective artery. Both veins run medially and merge to form the IVC. The left common iliac vein receives the middle sacral vein.

THE INTERNAL ILIAC VEIN, VENA ILIACA INTERNA

The internal iliac vein is the principal venous collector of the lesser pelvis. It drains the walls of lesser pelvis and all retaining viscera. Its short thick trunk ascends posterior to the artery of the same name and reaches the sacroiliac joint. There the vein joins the external iliac vein to give rise to the common iliac vein. The internal iliac vein receives the parietal and visceral tributaries. The visceral tributaries form the venous plexuses around the pelvic viscera.

The double **parietal tributaries** accompany the respective arteries. They are the *iliolumbar veins*, **venae iliolumbales**, the *superior gluteal veins*, **venae gluteae superiores**, the *inferior gluteal veins*, **venae gluteae inferiores**, the *obturator veins*, **venae obturatoriae** and the *lateral sacral veins*, **venae sacrales laterales**.

THE VENOUS PLEXUSES AND VISCERAL TRIBUTARIES OF THE LESSER PELVIS

The lesser pelvis contains the venous plexuses as follows:

1. The *rectal venous plexus*, **plexus venosus rectalis** surrounds the rectum. It is drained by the following veins:

- the *superior rectal veins*, **venae rectales superiores** join the inferior mesenteric vein (which belongs to the portal venous system);
- the *middle rectal veins*, **venae rectales medii** join the internal iliac vein;
- the *inferior rectal veins*, **venae rectales inferiores** join the internal pudendal vein (the tributary of the internal iliac vein).

The rectal venous plexus associates the IVC system with the portal venous system and thus constitutes the portocaval (the portal-systemic) anastomosis.

2. The *vesical venous plexus*, **plexus venosus vesicalis** occupies the fundus and the lateral aspects of the urinary bladder. The plexus is drained by the *vesical veins*, **venae vesicales** that open into the internal iliac vein;

3. The *prostatic venous plexus* ♂, **plexus venosus prostaticus** surrounds the prostate. It drains the seminal glands, prostate and penis. The plexus is drained by the by the vesical and middle rectal veins.

4. The *vaginal venous plexus* ♀, **plexus venosus vaginalis** surrounds the vagina. The plexus is drained by the vesical, uterine and middle rectal veins;

5. The *uterine venous plexus*, **plexus venosus uterinus** resides laterally from the uterus, in between the layers of the broad ligament of uterus. The plexus is drained by the *uterine veins*, **venae uterinae** (which open into the internal iliac vein) and the *ovarian veins* (they open into the IVC).

The perineum and external genitalia are drained by the *internal pudendal vein*, **vena pudenda interna** that opens into the internal iliac vein. Its tributaries correspond to the branches of the pudendal artery.

THE EXTERNAL ILIAC VEIN, VENA ILIACA EXTERNA

Relations of the external iliac vein

The external iliac vein is a direct continuation of the femoral vein. On passing the vascular space, the vein resides posterior and medial to the femoral artery. The external iliac vein joins the internal iliac vein to give rise to the common iliac vein.

The **tributaries of the external iliac vein** are like the following:

- the *inferior epigastric vein*, **vena epigastrica inferior** arises within the umbilical region (there it anastomoses with the superior epigas-

tric and para-umbilical veins). These interconnections give rise to the portocaval and cava-caval anastomoses. Descending as a single trunk along the inferior epigastric artery, the vein drains the anterior abdominal wall. Inferiorly, it anastomoses with the *obturator vein*;

- the *deep circumflex iliac vein,* **vena circumflexa ilium profunda** accompanies the artery of the same name and drains the respective area.

THE HEPATIC PORTAL VEIN, VENA PORTA HEPATIS

The hepatic portal vein is a great venous vessel (1.5-2 cm wide) that drains the unpaired abdominal viscera and carries the blood collected to the liver.

Practical issues

The blood drained from the intestines, stomach, pancreas and spleen passes through the hepatic capillaries before proceeding to the systemic circulation. This venous system serves the liver with its various important functions. The liver is responsible for synthesis and depositing of glycogen; it also plays a key role in metabolism of the proteins, lipids and vitamins. Detoxification belongs to one of the most important functions of liver because it neutralizes the toxic agents absorbed by the intestines together with the nutrients and water. Direct anastomosis between the IVC and HPV is fatal.

Relations of the HPV

The HPV resides within the hepatoduodenal ligament posterior to the common hepatic duct and hepatic artery. Its main trunk (4-5 cm long) arises posterior to the head of pancreas by the union of the superior and inferior mesenteric veins and the splenic vein (Fig. 113).

The *superior mesenteric vein,* **vena mesenterica superior** resides within the mesentery of the small intestine next to the mesenteric artery. Its tributaries correspond to the branches of neighboring artery. These branches are the *intestinal veins,* **venae intestinales**, the *right gastro-epiploic vein,* **vena gastroepiploica dextra**, the *pancreaticoduodenal veins,* **venae pancreaticoduodenales**, the *ileocolic vein,* **vena ileocolica** (with featured *appendicular vein,* **vena appendicularis**), the *right colic vein,* **vena colica dextra** and the *middle colic vein,* **vena colica media.** The superior mesenteric vein thus drains the entire small intestine, the caecum and vermiform appendix, the ascending and transverse colon, and partially the stomach, duodenum and pancreas.

The *inferior mesenteric vein,* **vena mesenterica inferior** also neighbors

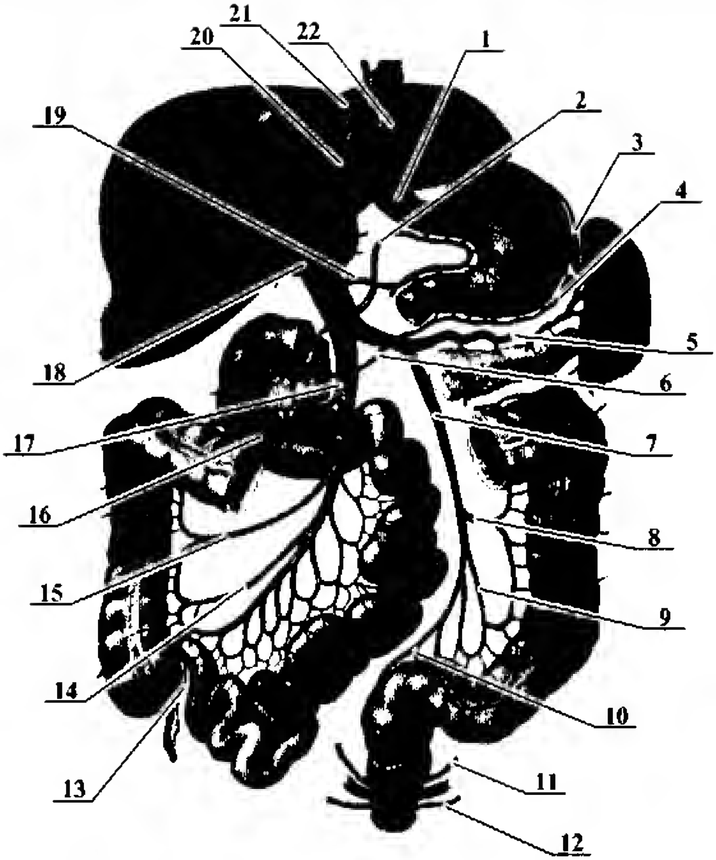


Fig. 113. The hepatic portal vein. 1 — vv. oesophageales; 2 — v. gastrica sinistra; 3 — vv. gastricae breves; 4 — v. gastroomentalis sinistra; 5 — v. splenica; 6 — v. gastroomentalis dextra; 7 — v. mesenterica inferior; 8 — v. colica sinistra; 9 — vv. sigmoideae; 10 — v. rectalis superior; 11 — vv. rectales mediae; 12 — vv. rectales inferiores; 13 — v. appendicularis; 14 — v. ileocolica; 15 — v. colica dextra; 16 — v. colica media; 17 — v. mesenterica inferior; 18 — v. porta hepatis; 19 — v gastrica dextra; 20 — vv. paraumbilicales; 21 — lig. falciforme hepatis; 22 — anulus umbilicalis.

the artery of the same name and its tributaries run next to the arterial branches. The tributaries are the *superior rectal vein*, **vena rectalis superior**, the *sigmoid veins*, **venae sigmoideae**, and the *left colic vein*, **vena colica sinistra**. The inferior mesenteric vein ascends posterior to the head of pancreas and opens into either splenic or superior mesenteric vein. The inferior mesenteric vein drains the upper portion of the rectum and the sigmoid and descending colon.

The *splenic vein*, **vena lienalis** becomes evident within the splenic hilum and proceeds rightwards, posterior to the pancreas. On reaching the head of pancreas, the vein joins the superior mesenteric vein. The splenic vein has the following tributaries: the *pancreatic veins*, **venae pancreaticae**, the *short gastric veins*, **venae gastricae breves** and the *left gastro-epiploic vein*, **vena gastroepiploica sinistra**. The splenic vein thus drains the spleen, pancreas and the stomach.

The tributaries of the main trunk

The main trunk of the HPV receives the tributaries as follows: the *right gastric vein*, **vena gastrica dextra**, the *left gastric vein*, **vena gastrica sinistra**, the *cystic vein*, **vena cystic**, the *prepyloric vein*, **vena prepylorica** and the *para-umbilical veins*, **venae paraumbilicales**.

The para-umbilical veins are the small vessels that occupy the round ligament of liver. In the umbilical region, the veins anastomose with the superior and inferior epigastric veins and with some subcutaneous veins (the *thoraco-epigastric veins* and the *superficial epigastric veins*). In portal obstruction, the para-umbilical veins become distended because they provide collateral circulation for blocked portal system. The blood thus drains to the veins of the anterior abdominal wall and further to the SVC and IVC.

THE INTRINSIC VASCULATURE OF LIVER

The liver receives the hepatic portal vein and the hepatic artery proper. The HPV is the functional blood vessel while the artery supplies the liver with oxygenated blood.

Within the liver, the HPV forks into the right and left branches that in turn split into the segmental branches. The segmental branches eventually become continuous with the interlobular branches and they give off radiating capillaries to the center of hepatic lobe. The capillaries merge into the central veins (they reside in the center of each lobule) that quit the lobule and join to form the *hepatic veins*, **venae hepaticae**. The hepatic veins constitute the efferent venous system of liver; they leave the liver within the groove for vena cava and open into the IVC.

Branches of the hepatic artery generally correspond to the branches of the HPV. The arterial precapillaries join the common lobular capillary network.

THE VEINS OF LOWER LIMB

The veins of the lower limb are subdivided into the superficial and deep. The superficial veins run below the skin and outside the proper fascia. The double deep veins accompany the arteries.

The **superficial veins** give rise to the great and small saphenous veins. They arise from the *dorsal* and *plantar venous networks of foot*:

- the *great saphenous vein*, **vena saphena magna** arises from the medial portion of the dorsal venous network of foot and ascend along the medial aspect of the leg and thigh (Fig. 114). In the upper third of thigh, the vein runs along its anterior surface to reach the *saphenous opening*. On passing the saphenous opening, the vein joins the femoral vein. On the way to destination point, the vein receives numerous tributaries that anastomose with each other and with the tributaries of small saphenous vein and deep veins of lower limb. At the *saphenous opening*, the vein receives the *external pudendal veins*, **venae pudendae externae**, the *superficial circumflex iliac vein*, **vena circumflexa ilium superficialis** and the *superficial epigastric vein*, **vena epigastrica superficialis**. These veins may join the femoral vein as well;
- the *small saphenous vein*, **vena saphena parva** arises at the lateral aspect of foot. The vein rounds the lateral malleolus and ascends along the posterior surface of leg in between the heads of the gastrocnemius muscle. At the popliteal fossa, the muscle pierces the fascia and joins the popliteal vein. The small saphenous vein receives numerous tributaries that anastomose with the tributaries of the great saphenous vein and with the deep veins of thigh.

The **deep veins** accompany the pertaining arteries (two veins accompany one artery). Therefore, two *anterior tibial veins*, **venae tibiales anteriores** accompany the anterior tibial artery, two *posterior tibial veins*, **venae tibiales posteriores** accompany the posterior tibial artery, etc. In the upper portion of leg, the anterior and posterior tibial veins merge to form a single *popliteal vein*, **vena poplitea**. The latter vein ascends to the adductor canal and becomes continuous with the femoral vein.

The *femoral vein*, **vena femoralis** resides within the femoral triangle medially from the femoral artery. Upon passing through the vascular space, it becomes continuous with the external iliac vein. The greatest tributary of the femoral vein is the *deep vein of thigh*, **vena profunda femoris**.

The deep veins anastomose with each other and with the superficial veins. Both superficial and deep veins have numerous valves.

Clinical applications

The *varicose veins* are distended, lengthened and tortuous veins. The state is caused by loose fascia, low resilience of vein wall and valve incompetence. The most commonly affected vein is the great saphenous vein yet other superficial veins are also susceptible. Treatment includes medication and surgical intervention (removal of the affected veins).

THE CAVA-CAVAL *ANASTOMOSES*

The cava-caval anastomoses associate the systems of the SVC and IVC. The most significant anastomoses reside by anterior and posterior abdominal walls.

The *vertebral venous plexuses*, **plexus venosus vertebralis interni et externi** are represented with wide anastomoses that reside all along the vertebral column.

The *sacral* and *lumbar veins* (they are related to the IVC system) drain the plexuses in the sacral and lumbar regions. The *vertebral, azygos* and *hemiazygos veins* (they belong to the SVC system) drain the plexuses in the cervical and thoracic regions.

The *azygos* and *hemiazygos veins* carry blood to the SVC. They represent another significant anastomosis because beginning of each vein (the *ascending lumbar veins*) is connected to the *lumbar veins* that join the IVC.

The **anterior abdominal wall** houses anastomosis between the *superior* and *inferior epigastric veins.*

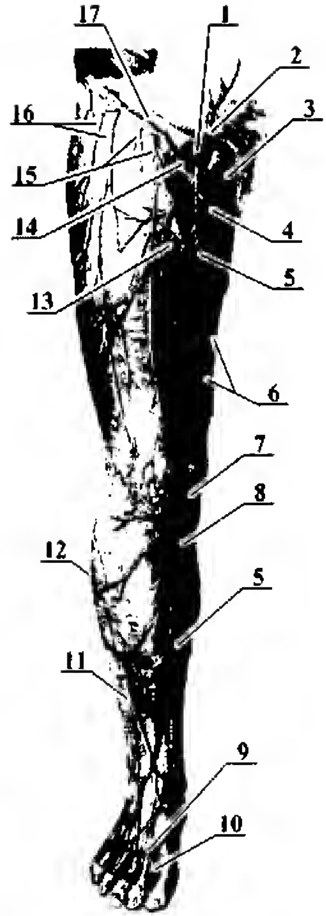


Fig. 114. The superficial veins and nerves of the right lower limb, anterior view.
1 — v. femoralis; 2 — v. epigastrica superficialis; 3 — vv. pudendae externae; 4 — v. saphena accessoria; 5 — v. saphena magna; 6 — rr. cutanei (n. obturatorius); 7 — r. infrapatellaris; 8 — n. saphenus; 9 — arcus venosus dorsalis pedis; 10 — vv. metatarsales dorsales; 11 — n. peroneus superficialis; 12 — n. cutaneus surae lateralis (n. peroneus profundus); 13 — rr. cutanei anteriores (n. femoralis); 14 — hiatus saphenus; 15 — r. femoralis n. genitofemoralis; 16 — n. cutaneus femoris lateralis; 17 — v. circumflexa iliaca superficialis.

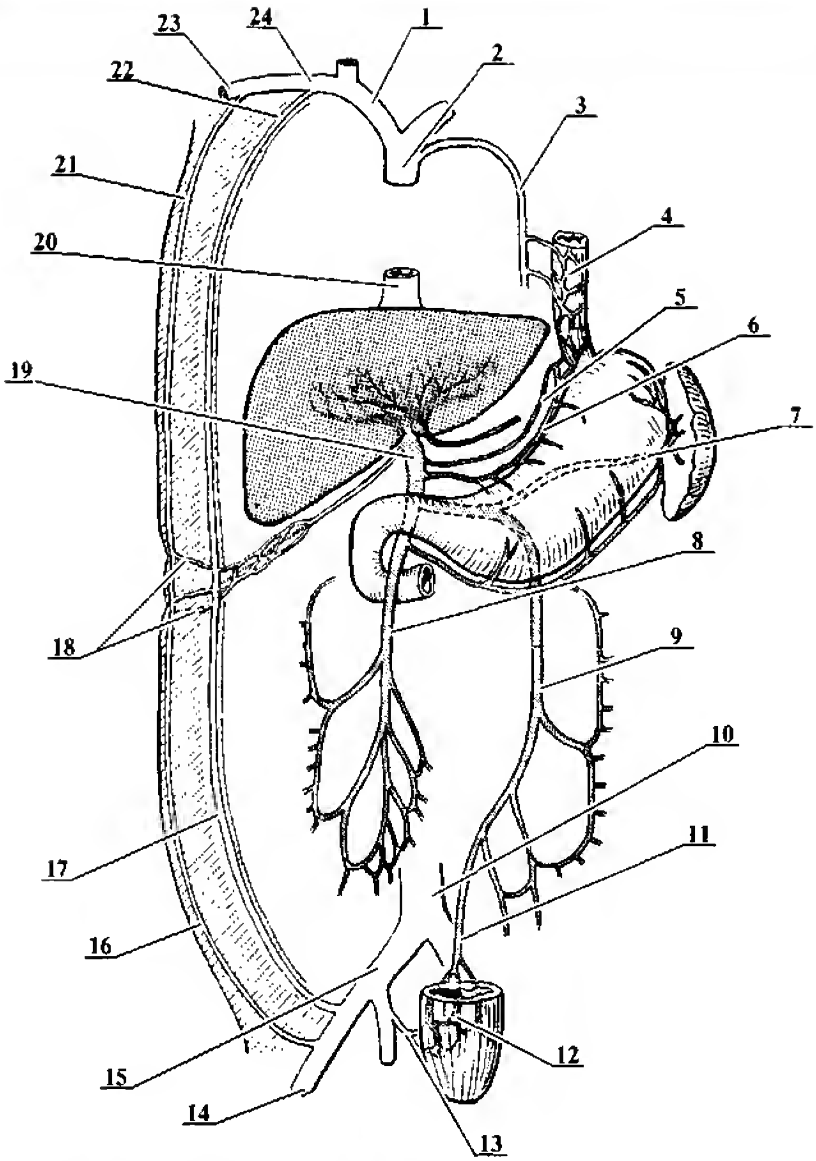


Fig. 115. The intersystem venous anastomoses (scheme). 1 — v. brachiocephalica; 2 — v. cava superior; 3 — v. azygos; 4 — vv. oesophageales; 5 — v. gastrica sinistra; 6 — v. gastrica dextra; 7 — v. lienalis; 8 — v. mesenterica superior; 9 — v. mesenterica inferior; 10 — v. cava inferior; 11 — v. rectalis superior; 12 — plexus venosus rectalis; 13 — vv. rectales media et inferior; 14 — v. femoralis; 15 — v. iliaca communis; 16 — v. epigastrica superficialis; 17 0 v. epigastrica inferior; 18 — vv. paraumbilicales; 19 — v. porta hepatis; 20 — v. cava inferior; 21 — v. thoracoepigastrica; 22 — vv. epigastricae superiores; 23 — v. axillaris; 24 — v. subclavia.

The superior vein carries blood to the *internal thoracic vein* (and thus to the SVC system) and the inferior one descends to join the external iliac vein (which belongs to IVC system).

The subcutaneous veins also anastomose by the anterior abdominal wall and the *thoraco-epigastric vein* joins the *axillary vein* while the *superficial epigastric vein* joins the *femoral vein.*

THE PORTOCAVAL ANASTOMOSES

The portocaval anastomoses associate the HPV with either SVC or IVC (Fig. 115). The most significant anastomoses are like the following:

The **esophagus and stomach** house anastomosis between the *oesophageal* and *left gastric veins.* The oesophageal veins carry blood to the *azygos* and *hemiazygos veins*; the left gastric vein opens into the HPV.

The **rectum** houses anastomosis between the *superior, middle and inferior rectal veins.* The superior rectal vein joins the *inferior mesenteric vein* (which belongs to the HPV system) and the middle and inferior rectal veins join the internal iliac artery (and it belongs to the IVC system).

The *para-umbilical veins* that run along the **round ligament of liver** join the HPV. Within the umbilical region, the para-umbilical veins anastomose with the veins of anterior abdominal wall. The latter veins join the SVC and IVC systems.

EVOLUTION OF CIRCULATORY SYSTEM

Circulatory organs in invertebrates

Homeostasis maintenance becomes possible only with fluid circulation (otherwise, the systems of an organism will experience dissociation). In inferior invertebrates, nutrients intake and withdrawal of waste products occur due to plain diffusion via the integuments. In these animals, fluids take no circulatory route. Next evolutional step constitutes formation of vessels within the connective tissue. The open-type circulatory system is the first to develop. Here blood quits the blood vessels to pass through slit-like spaces (lacunae) around the viscera and within the tissues. Blood flow is provided by contractions of body muscles and muscular fibers of blood vessels.

Further on, the muscular layer of a certain vascular segment undergoes additional development. Such pulsating vessel works similarly to heart.

The annelids and chordates are the first to develop closed-type circulatory system.

Circulatory system in lancelet

Lancelet has no heart; colorless blood circulates within closed-type circulatory system. Lancelet has two

great vessels: the abdominal and spinal. The pulsating abdominal vessel called the abdominal aorta forces deoxygenated blood to cranial end of body. The abdominal aorta gives branches to the gills. Oxygenated blood runs to paired suprabranchial vessels that merge into a single dorsal aorta that runs all along the body below the notochord. The dorsal aorta gives segmental arteries to muscles and branches to respective viscera.

Comparative anatomy of heart

Origination of heart

The cyclostomes and fish are the first to develop heart as a specialized segment that forces blood. The heart has two principal chambers — a thin-walled atrium and a ventricle with thicker walls. The veins merge into a sac-like *venous sinus* (**sinus venosus**), which opens into the atrium. Deoxygenated blood proceeds to the ventricle, which is continuous with the *conus arteriosus* (Lat. Id.). The conus in turn is continuous with the abdominal aorta. The abdominal aorta splits into afferent branchial arteries that join the capillary networks in the gills. These capillary networks are responsible for oxygenation of blood. Oxygenated blood runs via efferent branchial arteries to paired suprabranchial arteries that merge into a single dorsal aorta.

In inferior vertebrates thus, the heart pumps only deoxygenated blood. Oxygenation occurs within the branchial capillary network. Such two-chamber heart comprises four compartments separated by the valves: the venous sinus, the atrium, the ventricle and the conus arteriosus.

Transformations in heart in terraneous vertebrates

Major changes occur in CVS after the animals change inhabitancy and develop lungs instead of gills.

In amphibians, the atrium partitions into the venous (right) and arterial (left) halves by means of the interatrial septum. The ventricle however *remains non-partitioned and heart* thus appears to be three-chambered. The conus arteriosus that carries the blood away from the ventricle is continuous with a common aortic trunk. The aortic trunk is separated into the ventral and dorsal compartments. The ventral compartment gives rise to the carotid arteries and dorsal aorta. The dorsal compartment gives rise to cutaneous-pulmonary artery that carries blood to skin and lungs.

The reptiles develop incomplete inter ventricular septum in addition to the interatrial septum. The conus arteriosus is reduced; the aortic trunk arises directly from the ventricle. The trunk splits into three vessels: the pulmonary artery and two aortic arches (left and right). The pulmonary artery arises from the right portion of the ventricle. The aortic arches run posteriorly and merge into a single aorta right below the vertebral column. The venous sinus in reptiles fuses with the right atrium. In superior reptiles like crocodiles, the ventricles are separated by interventricular septum and heart

thus becomes four-chambered. The upper portion of the interventricular septum still has a small opening (**foramen Panizzae**) that communicates the ventricles. In birds and mammals, the heart completes partitioning and features four individual chambers. The right ventricle gives rise to the pulmonary trunk that splits into the right and left pulmonary arteries. The left ventricle gives rise to the aorta. The birds retain the right aortic arch, the mammals – the left.

The birds and mammals thus feature complete separation of arterial and venous blood flows. All organs and tissues are supplied solely with arterial (oxygenated) blood.

Comparative anatomy of arteries

The branchial aortic arches

In inferior vertebrates that breathe with gills, blood oxygenation occurs in branchial capillaries. The branchial arteries thus are the principal arteries that specify structural features of CVS in these animals.

The venous blood reaches the branchial capillaries via afferent branchial arteries that arise from the ventral aorta. The arterial blood quits the capillary network via efferent branchial arteries that join the dorsal aorta. Both afferent and efferent arteries appear as aortic arches that associate the ventral and dorsal aortas. These arches reside within the respective branchial arches. They are interrupted by the branchial capillaries.

During embryonic development, all vertebrates (including humans) develop primordia of six branchial aortic arches. The arches are marked with Roman numeric characters (I-VI). However, in fish the I and II arches disappear and adult animals retain four pairs of arches – III through VI.

In fish, the first (III) efferent arch gives rise to the carotid arteries that supply brain, eyes and other cranial organs. Other efferent branchial arteries merge into paired suprabranchial arteries that give rise to a single dorsal aorta.

Transformation of arteries in terraneous vertebrates

Amphibians and reptiles lose gills and this leads to partial reduction and transformation of branchial arteries. The I, II and V pairs of branchial arteries (aortic arches) reduce completely while the III (first) branchial artery detaches from the dorsal aorta and gives rise to the carotid arteries. The IV (second) pair of arteries transforms into paired aortic arch. Merging of paired aortic arch gives rise to the systemic dorsal aorta. The V pair disappears and the VI pair transforms into the pulmonary arteries. The inferior terraneous vertebrates thus feature two aortic arches that run posterior to the heart and merge to form unpaired aorta. The aorta gives somatic and visceral branches.

In birds, the left aortic arch (better developed in reptiles) reduces while the right arch persists. In mammals, on the contrary, the right arch disappears and the left one continues development. Initial symmetry of arterial vessels becomes violated in supe-

rior vertebrates (birds and mammals). In mammals, the residual right aortic arch gives rise to the brachiocephalic trunk and right subclavian artery.

Comparative anatomy of venous vessels

The hepatic and renal portal systems

In fish, venous blood drained from intestines runs to the liver via the hepatic portal vein, which splits into capillaries within the liver. The capillary network gives rise to the efferent hepatic veins that join the venous sinus.

Apart from common hepatic portal system, the inferior vertebrates feature the renal portal system. The venous blood drained from the caudal portion of body reaches the kidneys via the caudal vein. The latter artery gives afferent renal portal veins within hilum of each kidney. The veins split into capillary network that gives rise to the efferent renal veins each of which is continuous with a longitudinal vein called the *posterior cardinal vein*.

The cardinal veins and Cuvier's ducts

In fish, the efferent renal veins run forth draining the body walls via the segmental veins. These veins are principal venous vessels that drain the caudal portion of body and thus they are called the posterior cardinal veins.

The cranial portion of body is drained by paired short anterior cardinal (jugular) veins. On reaching the heart, each pair o veins merge to form two shorter common cardinal veins (Cuvier's) ducts that join the venous sinus.

Transformation of veins in terraneous vertebrates

Symmetrical arrangement of anterior and posterior cardinal veins becomes altered in superior fish. In dipnoans, the posterior cardinal veins give rise to a new vein – the posterior vena cava that joins the venous sinus.

In terraneous vertebrates, the posterior vena cava become the principal vein that drains the caudal portion of body instead of the posterior cardinal veins that become less significant for these purposes. Residual posterior cardinal veins transform into the azygos and hemiazygos veins. In superior vertebrates, the renal portal system disappears and the renal veins join the IVC.

The anterior cardinal veins and Cuvier's ducts transform into the left and right anterior venae cavae. They give rise to the jugular and subclavian veins.

Many mammals (and humans) develop anastomosis between the left and right anterior venae cavae (the brachiocephalic vein). The left anterior vena cava reduces and the right Cuvier's duct joins the right anterior vena cava. The left duct reduces yet incompletely and eventually gives rise to the coronary sinus. Vestigial left anterior vena cava in humans is represented with the oblique vein of left ventricle.

Practice questions

1. Give general description of the aorta. Describe the aortic arch and name its branches.
2. Describe the common carotid artery (both left and right).
3. Describe the external carotid artery.
4. Describe the anterior branches of the external carotid artery.
5. Describe the facial artery.
6. Describe the posterior branches of the external carotid artery.
7. Describe the medial branches of the external carotid artery.
8. Describe the superficial temporal artery.
9. Describe the maxillary artery.
10. Describe the internal carotid artery.
11. Describe the subclavian artery.
12. Describe the basilar artery.
13. Describe the cerebral arterial circle.
14. Describe the axillary artery.
15. Describe the brachial artery.
16. Describe the radial artery.
17. Describe ulnar artery.
18. Describe the cubital anastomosis.
19. Describe the superficial palmar arch
20. Describe the deep palmar arch.
21. Describe the dorsal carpal arch.
22. Describe the palmar carpal arch.
23. Describe the palmar arterial anastomoses.
24. Describe the thoracic aorta.
25. Give general description of the abdominal aorta.
26. Describe the parietal branches of the abdominal aorta.
27. Describe the paired and unpaired visceral branches of the abdominal aorta.
28. Describe the intersystem and intrinsic anastomoses of the branches of abdominal aorta.
29. Describe the common iliac artery.
30. Describe the parietal branches of the internal iliac artery.
31. Describe the visceral branches of the internal iliac artery.
32. Describe the external iliac artery.
33. Describe the femoral artery.
34. Describe the deep artery of thigh.
35. Describe the popliteal artery.
36. Describe the anterior tibial artery.
37. Describe the posterior tibial artery.
38. Describe the genicular anastomosis.
39. Describe the medial plantar artery.
40. Describe the lateral plantar artery.
41. Describe the dorsal artery of foot.
42. Describe the arterial anastomoses of foot.
43. Discuss arrangement regularities of the veins. Give definition of the root veins and tributary veins.
44. Describe the superior vena cava.
45. Describe the internal jugular vein.
46. Describe the intracranial tributaries of the internal jugular vein.
47. Describe the extracranial tributaries of the internal jugular vein.

48. Describe anastomoses between the intracranial and extracranial tributaries of the internal jugular vein.
49. Describe the venous angle.
50. Describe the external jugular vein.
51. Describe the anterior jugular vein and the jugular venous arch.
52. Describe the brachiocephalic vein.
53. Give general description and classification of the veins of upper limb. Describe the superficial veins.
54. Describe the deep veins of upper limb. Discuss their features.
55. Describe the axillary vein.
56. Describe the azygos vein.
57. Describe the hemiazygos vein.
58. Describe the accessory hemiazygos vein.
59. Describe the intercostal veins.
60. Describe the veins of vertebral column.
61. Describe the inferior vena cava.
62. Describe the visceral tributaries of the inferior vena cava.
63. Describe the parietal branches of the inferior vena cava.
64. Describe the hepatic portal vein.
65. Describe the internal iliac vein.
66. Describe the parietal tributaries of the internal iliac vein.
67. Describe the external iliac vein.
68. Give general description of the veins of lower limb. Describe the superficial veins of the lower limbs.
69. Describe the great saphenous vein.
70. Describe the deep veins of lower limb.
71. Describe the femoral vein.
72. Describe the venous plexuses of lesser pelvis.
73. Give definition of intrinsic and intersystem venous anastomoses.
74. Describe the portocaval anastomoses at the esophagus.
75. Describe portocaval anastomoses at the rectum.
76. Describe the portocaval anastomoses by the posterior abdominal wall.
77. Describe the cava-caval anastomoses by the anterior abdominal wall.
78. Describe the porto-cava-caval anastomosis by the anterior abdominal wall.
79. Describe the cava-caval anastomosis by the posterior abdominal wall.
80. Describe the cava-caval anastomosis along the vertebral column.

THE LYMPHOID SYSTEM, SYSTEMA LYMPHOIDEUM

The *lymphoid system,* **systema lymphoideum** is tightly associated with the cardiovascular system and thus constitutes a part of a joint cardiovascular and immune systems.

Terminology: the term originates from Latin word '**lympha**' – 'spring water' and Greek word '**nympha**' – 'bride' or 'goddess of springs, forests and mountains'.

Functions of the lymphoid system

The lymphatic capillaries absorb the interstitial fluid that contains the products of cellular metabolism, lymphocytes, sometimes red blood cells and several foreign substances in part fragments of dead cells, mutant cells, microorganisms, viruses etc. The lymph nodes are responsible for withdrawal of these products. The macrophages absorb and process the antigens to pass antigen data to plasmatic cells. The antigens trigger this mechanism of antigen dependent proliferation and differentiation of T- and B-lymphocytes and generation of immune response. The lymphoid system thus features protective function.

Lymph, **lympha** is made up of interstitial fluid absorbed by lymphatic capillaries. It is a clear colorless fluid similar to blood plasma yet low in protein. The principal cellular elements of lymph are the lymphocytes (96-98 %). Normally, lymphatic system of an adult individual contains about 2 liters of lymph. After a meal (especially reach in fats), lymph drained from small intestine has milky appearance (*milky juice,* **chylus**). Greek word '**chylus**' stands for 'artificial juice'. This term was coined for lymph of intestinal lymphatic capillaries.

Clinical applications

In many diseases, pathogens and malignant cells disseminate via the lymphatic vessels. Studying of lymph circulation and location of regional lymph nodes thus is of great importance for diagnostics, treatment and prognosis of inflammatory diseases and malignancies. Clinical specialists employ lymphatic injections, optic fibers for laser microsurgery and lymph absorption.

Historical notes

The lymphatic vessels were discovered by Italian anatomist of the 17th century Gasparo Azelli (1581-1626). In 1622, while demonstrating diaphragm movements in living dog, he noticed mesenteric vessels filled with whitish fluid. Later, he found out that dog had a fatty meal before. Azelli called these vessels 'milky vessels' and believed them to carry 'white blood' or 'milky juice' (chylus) to the liver. Later, after Azelli's death, these vessels were described as a tubular system that drains lymph to venous flow.

Functional significance of the thoracic duct known as the 'white

vein' was studied by student of University of Paris J. Peques (1622-1674). After experimental studies, he found out that the thoracic duct drains the thoracic and abdominal viscera and joins the cervical veins. The thoracic duct in humans was described by O. Rudbek (1651) and F. Bartholini (1652).

Owing to extensive studies of such prominent anatomists as P. Moscagni (1787), F. Sappey (1885) G. M. Iosifov (1870-1933), G. Ruvier (1932), D. A. Zhdanov (1908-1972) and especially F. A. Stefanis (1865-1917), M. S. Spirov (1896-1972), A. A. Sushko (1899-1970) and O. I. Sviridov (1900-1973) (they belong Kiev lymphology school) study of lymphoid system came to being.

The lymphoid system comprises the primary and secondary lymphoid organs and the lymphatic vessels.

The *primary lymphoid organs*, **organa lymphoidea primaria** comprise the organs as follows:

- the *red bone marrow*, **medulla ossium rubra** (analogue bursa of Fabricius in birds) is responsible for antigen independent proliferation and differentiation of B-lymphocytes;
- the *thymus* (Lat. Id.) is responsible for antigen independent proliferation and differentiation of T-lymphocytes;

T- and B-lymphocytes further infiltrate T- and B-dependent zones within the secondary lymphoid organs where targeting immune response is generated.

The *secondary lymphoid organs*, **organa lymphoidea secundaria** comprise the following organs:

- the *lymph nodes*, **nodi lymphoidei**;
- the *tonsils* related to the pharynx. They are six tonsils – paired *palatine tonsils*, **tonsilla palatina**, paired *tubal tonsils*, **tonsilla tubaria**, single *lingual tonsil*, **tonsilla lingualis** and single *pharyngeal tonsil*, **tonsilla pharyngea**. The tonsils form the *pharyngeal lymphoid ring*, **anulus lymphoideus pharyngeus**. These organs are made up of lymphoid tissue. The lymphoid tissue groups into numerous *lymphoid nodules*, **noduli lymphoidei**;
- the lymphoid tissue related to the alimentary, respiratory and urinary systems. Mucosa and submucosa of these systems contain the *solitary lymphoid nodules*, **noduli lymphoidei solitarii** (1.5-2 mm). Five or more solitary nodules constitute *aggregated lymphoid nodules*, **noduli lymphoidei aggregati**. The aggregated nodules are also called the lymphoid patches or the Peyer's patches. The ileum contains many such patches yet they are found in other segments of small intestine. The patches are 0.2 to 15 cm long and 0.2-1.5 cm wide;
- the *vermiform appendix*, **appendix vemiformis** contains up to 550 lymphoid nodules within the mucosa and submucosa. The nodules are variable in shape and size (0.2-1.2 cm);
- the *spleen*, **splen (lien)** namely its white pulp, which consists of lym-

phoid nodules and lymphoid periarterial sheaths.

The secondary lymphoid organs are responsible for antigen dependent proliferation and differentiation of both T- and B-lymphocytes that participate in immune response.

THE LYMPHATIC PATHWAYS

The lymphoid system is represented with branching lymphatic capillaries, lymphatic retes, lymphatic vessels, lymphatic trunks and lymphatic ducts. These pathways are interrupted by cascades of numerous lymph nodes, which serve lymph filtering (Fig. 116).

The *lymphatic capillaries*, **vasa lymphocapillaria**

The lymphatic capillaries constitute an initial segment of the lymphatic system (Fig. 117). The morphological features of the lymphatic capillaries are like the following:

- they are closed-end tubes that provide only one-way flow route; the capillaries from anastomosing networks within the organs;
- the lumen of a typical lymphatic capillary is of irregular diameter i.e. one can see dilated (100-200 μm) and narrowed (8-10 μm) segments in one and the same capillary. The capillaries also feature side evaginations — lacunae or lacs;
- the wall of a lymphatic capillary consists of a single endothelial layer (0.3 μm thick). The basal membrane and pericytes are absent so the lymphatic capillary is a semi-permeable membrane;
- the lymphatic capillaries attach to adherent collagen fibers by means of anchor (sling) filaments, which keep the lumen open even in swollen tissues. This is necessary for continuous drainage of interstitial fluid.

The spinal cord and brain with featured meninges, the cartilages, the lymphoid organs and the placenta have no lymphatic capillaries.

The *lymphatic rete*, **rete lymphocapillare**

The lymphatic capillaries anastomose to form closed lymphatic retes (Fig. 118).

Architecture, orientation and density of the capillaries vary depending on the organ drained. Muscles, lungs, kidneys, liver etc feature three-dimensional lymphatic networks while flat structures (the fasciae, serous investments and walls of hollow organs) feature two-dimensional networks. Appearance of the retes depends on structure of pertaining stroma.

The *lymphatic vessels*, **vasa lymphatica**

The lymphatic vessels drain the lymphatic retes (Fig. 119). Their

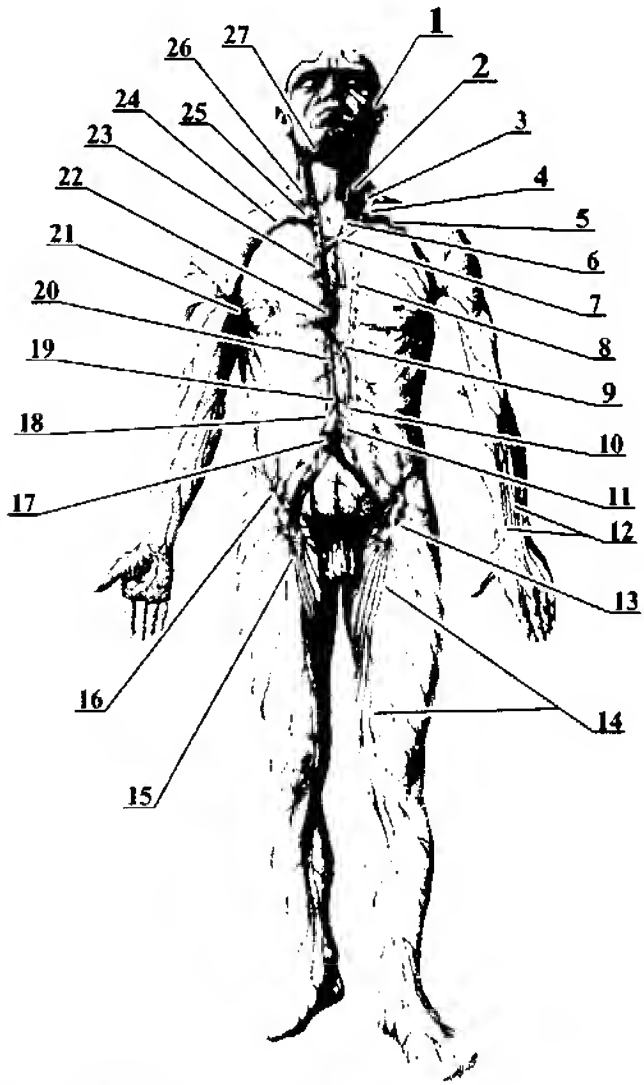


Fig. 116. The lymphatic system in humans (scheme). 1 — nodi lymphoidei parotidei; 2 — v. jugularis interna; 3 — truncus jugularis sinister; 4 — truncus subclavius sinister; 5 — v. subclavia sinistra; 6 — ductus thoracicus (pars cervicalis); 7 — v. brachiocephalica sinistra; 8 — nodi lympoidei intercostales; 9 — v. hemiazygos; 10 — truncus lumbalis dexter; 11 — truncus intestinalis; 12 — vasa lymphoidea superficiales membri superioris; 13 — nodi lymphoidei iliaca externi; 14 — vasa lymphoidea superficiales membri inferioris; 15 — nodi lymphoidei inguinales profundi; 16 — nodi lymphoidei inguinales superficiales; 17 — v. cava inferior; 18 — truncus lumbalis dexter; 19 — cisterna chyli; 20 — v. azygos; 21 — nodi lymphoidei axillares; 22 — ductus thoracicus (pars thoracicus); 23 — v. cava superior; 24 — ductus subclavius dexter; 25 — ductus lymphaticus dexter; 26 — ductus jugularus dexter; 27 — nodi lymphoidei submandibulares.

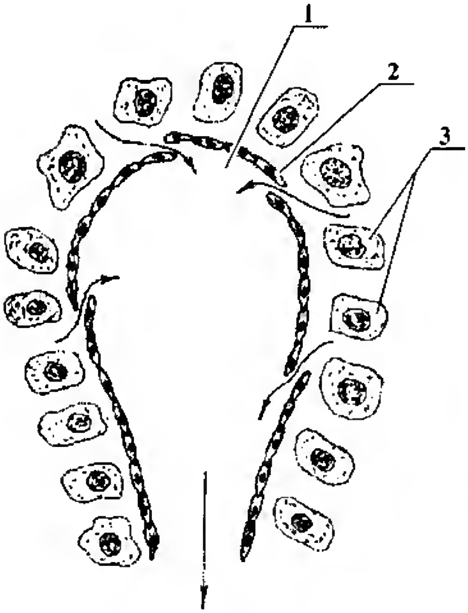


Fig. 117. Structure of a lymphatic capillary (scheme). 1 — the lymphatic capillary, 2 — the endothelium, 3 — the cells adherent to the capillary. Movement of interstitial fluid and lymph is shown with arrows.

Fig. 118. Structure of lymphatic capillary network (scheme). 1 — the lymphatic capillary, 2 — the capillary network

walls feature connective tissue (muscle-free vessels) in addition to common endothelial layer. These small lymphatic vessels are 30-40 μm wide. The greater vessels have a middle muscular layer that thickens with vessel diameter increase. The medium and large lymphatic vessels feature three well-developed layers — the endothelial, muscular and adventitial and thus appear as muscle-type vessels.

The lymphatic vessels feature the *lymphatic valvules,* **valvulae lymphaticae** — paired endothelial folds (cusps) directed towards each other. A segment delimited by two valves is called the lymphangion. Segment length varies from 2-3 mm in smaller intrinsic vessels to 12-15 mm in greater extrinsic vessels. Valve-related sites are narrow so the lymphatic vessels are necklace-shaped. Rhythmic muscular contractions assisted by valves force lymph upwards. The intrinsic lymphatic vessels anastomose to form the *lymphatic plexuses,* **plexus lymphaticus.**

The lymphatic vessels are subdivided into superficial and deep. The *superficial lymph vessels,* **vasa lymphatica superficialia** reside within the subcutaneous tissue outside the superficial fascia. They collect lymph

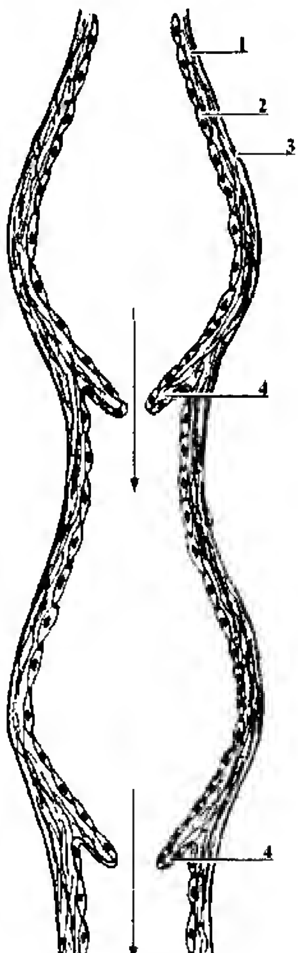


Fig. 119. **Structure of lymphatic vessel (scheme).** 1 – the lymphatic capillary, 2 – the endothelium, 3 – the adventitia. Movement of lymph is shown with arrows.

from skin, subcutaneous tissue and fasciae. The *deep lymph vessels*, **vasa lymphatica profunda** drain the bones, joints, muscles, deep fasciae and viscera. The deep lymph vessels accompany blood vessels and nerves of the respective regions. In movable areas, the vessels split to form numerous collateral vessels in order to ensure uninterrupted lymph flow around joints.

On the way to venous system, the lymphatic vessels are interrupted by the lymph nodes (See page 343). With the respect to nodes, the *afferent lymph vessels*, **vasa lymphatica afferentia** and *efferent lymph vessels*, **vasa lymphatica efferentia** are distinguishable. The convex aspect of the lymph node receives 2 to 4 (or more) afferent vessels that pierce the capsule and open into the subcapsular (marginal) sinus. The lymph passes through the entire node via the system of intermediate sinuses picking up the lymphocytes from the node parenchyme. The hilum of node passes 1 or 2 efferent vessels that run to next nodes or to the lymph collectors – the trunks or ducts. The nodes that form regional group anastomose via the lymph vessels. These vessels pass lymph to the next node in the chain, always in direction of the venous angles formed of the internal jugular and subclavian veins. Lymph thus passes at least one node yet normally it passes a cascade of nodes. For instance, lymph collected from the stomach passes 6 to 8 nodes, lymph from kidney passes 6 to 10 nodes; 8 to 10 nodes are needed to filter lymph collected from the lower limb. The lymph vessels are absent in the brain and spinal cord with related meninges, the spleen, the cartilages, the eyeball and the red bone marrow.

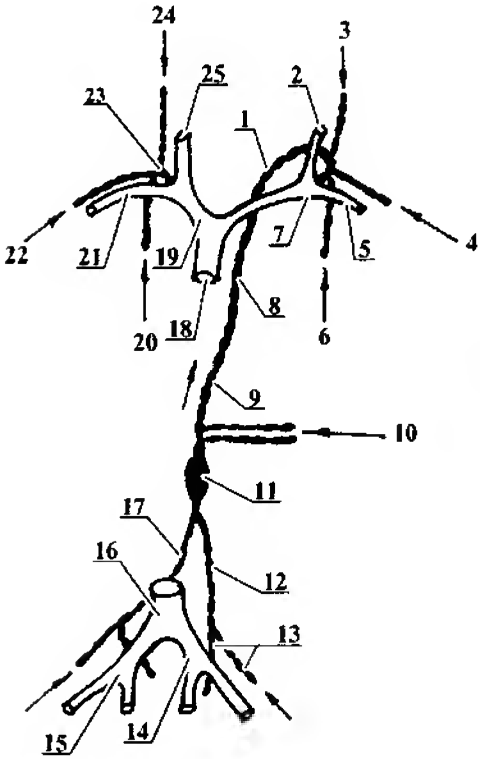


Fig. 120. The lymphatic trunks and ducts (scheme). 1 – pars cervicalis ductus thoracici; 2 – v. jugularis interna sinistra; 3 – truncus jugularis sinister; 4 – truncus subclavius sinister; 5 – v. subclavia sinistra; 6 – truncus bronchomediastinalis sinister; 7 – v. brachiocephalica sinistra; 8 – pars thoracica ductus thoracici; 9 – pars abdominalis ductus thoracici; 10 – trunci intestinales; 11 – cisterna chyli; 12 – truncus lumbalis sinister; 13 – vasa lymphatica iliaci; 14 – v. iliaca communis sinistra; 15 – v. iliaca communis dextra; 16 – v. cava inferior; 17 – truncus lumbalis dexter; 18 – v. cava superior; 19 – v. brachiocephalica dextra; 20 – truncus bronchomediastinalis dexter; 21 – v. subclavia dextra; 22 – truncus subclavius dexter; 23 – ductus lymphaticus dexter; 24 – truncus jugularis dexter; 25 – v. jugularis interna dextra. Movement of lymph is shown with arrows.

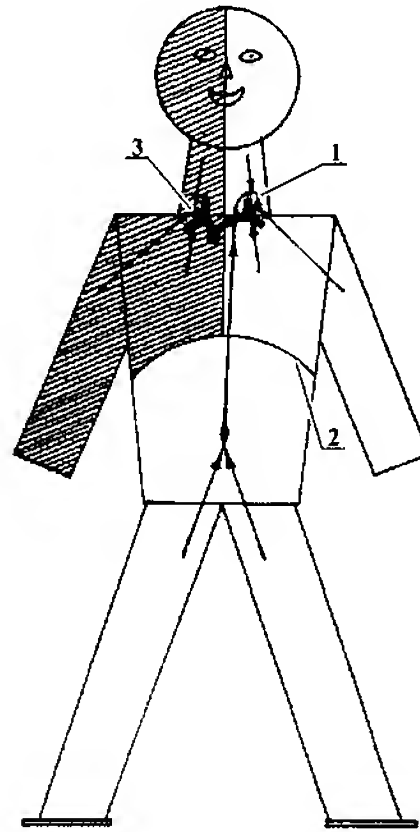


Fig. 121. Lymph drain to the lymphatic ducts (scheme). 1 – the thoracic duct, 2 – the diaphragm, 3 – the right lymphatic duct (the shaded area corresponds to the regions drained by this duct). Movement of lymph is shown with arrows.

The *lymphatic trunks*, **trunci lymphatici**

The lymph vessels merge to form the **lymphatic trunks**, which collect lymph from certain regions of body to the lymphatic ducts (Fig. 120, 121).

The trunks distinguishable are like the following:

The *jugular trunk (left and right)*, **truncus jugularis (dexter et sinister)** arises from the efferent vessels of lateral deep cervical nodes. It collects lymph from the respective side of the head and neck. The right jugular trunk opens either into the right lymphatic duct, or into the right venous angle, or into the terminal portion of the right internal jugular vein. The left jugular trunk opens either into the cervical portion of the thoracic duct, or into the left venous angle, or into the terminal portion of the left jugular vein.

The *subclavian trunk (left and right)*, **truncus subclavius (dexter et sinister)** arises from the efferent lymph vessels given by the axillary lymph nodes. It drains the respective upper limb. The right subclavian trunk opens either into the right lymphatic duct, or into the right venous angle, or into the terminal portion of the right subclavian vein. The left duct opens either into the terminal portion of the thoracic duct, or into the left venous angle, or into the left subclavian vein.

The *bronchomediastinal trunk (left and right)*, **truncus bronchomediastinalis (dexter et sinister)** arises from the efferent lymph vessels given by the tracheobronchial lymph nodes. The trunks drain the parietal and visceral vessels of the respective side. The right trunk opens either into the right lymphatic duct, or into the right venous angle; the left trunk opens either into the terminal portion of the thoracic duct, or into the left venous angle.

The *lumbar trunk (left and right)*, **truncus lumbalis (dexter et sinister)** arises from the efferent lymph vessels given by the lumbar lymph nodes that surround the abdominal aorta and the IVC. The lumbar trunks collect lymph from the respective lower limb, and from the pelvic walls and pelvic viscera. The lumbar trunks merge to form the thoracic duct.

The *intestinal trunks*, **trunci intestinales** are several irregular trunks (distinguished in about 25% of individuals) that arise from the efferent lymph vessels given by the mesenteric nodes. The intestinal trunks open either into the thoracic duct, or into the lumbar trunks.

The **lymphatic ducts** arise from merging lymphatic trunks. The ducts distinguished are the right lymphatic duct and the thoracic duct.

The *right lymphatic duct*, **ductus lymphaticus dexter** is an irregular vessel about 10-15 cm long. It arises from merging right bronchomediastinal, jugular and subclavian trunks. The duct opens into the right venous angle. In 80% of occurrences, the right lymphatic duct is absent and the trunks reach the respective veins separately.

The right lymphatic duct receives lymph from the right side of the head and neck, from the right upper limb and from the thoracic walls and viscera on the right.

The *thoracic duct*, **ductus thoracicus** arises within the retroperitoneal fat from merging lumbar trunks, which meet at the level of Th12 or L2. The intestinal trunks may participate in formation of the trunk as well. The thoracic duct is about 30-40 cm long. It has the abdominal, thoracic and cervical parts.

The *abdominal part*, **pars abdominalis** in 75% of individuals begins with dilated segment called the *cysterna chili* (Lat. Id.). In absence of the cysterna, the beginning of the duct appears as a lymphatic plexus formed of several lymphatic trunks. The abdominal part resides posteriorly and to the right from the abdominal aorta. It attaches to the right crus of the diaphragm and its continuous movements force lymph along the duct. The thoracic duct enters the posterior mediastinum via the aortic hiatus.

The *thoracic part*, **pars thoracica** resides anterior to the vertebral column, in between the aorta and the azygos vein, and posterior to the oesophagus. In the upper portion of the thoracic cavity, the duct declines leftwards and enters the cervical region via the thoracic inlet. The thoracic duct receives the efferent vessels given by the intercostal and mediastinal lymph nodes.

The *cervical part*, **pars cervicalis** arches leftwards at the level of C5 or C7, loops around the left cervical pleura and joins the left venous angle or any pertaining vein. The cervical part of the thoracic duct receives the left jugular, subclavian and bronchomediastinal trunks. These trunks often bypass the duct and join the veins directly. The outlet of the duct features a paired valve. The valve prevents the venous blood from entering the duct. The duct features 7-9 valves. The valves and muscular layer assist in forcing of blood. In 50% of occurrences, the terminal portion of the duct dilates or even bifurcates. The thoracic duct drains both lower limbs, the left portion of the abdominal cavity with related viscera, the left portion of the thoracic cavity, the right side of the head and neck and the left upper limb.

Lymph collected from various regions of body thus eventually appears within two ducts – the right lymphatic and thoracic ones. The ducts open into the venous angles on the respective side.

Clinical applications

Knowledge of topography and structural variability of the thoracic duct is of great necessity for clinical specialists. Some diseases like peritonitis or burn disease are complicated with general intoxication of the organism. In such cases, drainage of the thoracic duct with following lymph purification is included into conventional detoxicaton procedures.

THE REGIONAL LYMPH NODES AND VESSELS

THE LYMPH NODES AND VESSELS OF HEAD AND NECK

Lymph from the head and neck passes to the lymph nodes that occupy certain regions and form regional groups. The efferent vessels given by these nodes run to the superficial and deep cervical nodes that also receive lymph vessels from the cervical viscera (Fig. 122).

The *lymph nodes of head*, **nodi lymphoidei capitis** form the following regional groups:

- the *occipital nodes*, **nodi occipitales** (1-6) receive the afferent lymph vessels from the occipital and temporal regions. Their efferent vessels pass to the lateral deep cervical nodes;
- the *mastoid nodes*, **nodi mastoidei** (1-4) receive the afferent lymph vessels from the occipital and parietal regions, and from the external ear. Their efferent vessels pass to the superficial and deep lateral cervical nodes;
- the *superficial parotid nodes*, **nodi parotidei superficiales** (1-4) and *deep parotid nodes*, **nodi parotidei profundi** (4-10) (the latter group includes the *pre-auricular nodes*, **nodi preauriculares**, *infra-auricular nodes*, **nodi infraauriculares** and the *intraglandular nodes*, **nodi intraglandulares**). This group receives lymph vessels from the frontal and parietal regions, eyelids, nose, cheeks, auricle and parotid gland. Their efferent vessels pass to the superficial and deep cervical lymph nodes;
- the *facial nodes*, **nodi faciales** are four nodes as follows: the *buccinator node*, **nodus buccinatorius**, the *nasolabial node*, **nodus nasolabialis**, the *malar node*, **nodus malaris** and the *mandibular node*, **nodus mandibularis**. These nodes receive lymph from the eyelids, nose, cheeks and upper lip;
- the *submental nodes*, **nodi submentales** (1-8) and *lingual nodes*, **nodi linguales** receive the efferent vessels from the chin, lower lip and tongue. Their efferent vessels pass to the anterior cervical nodes;
- the *submandibular nodes*, **nodi submandibulares** (6-8) reside within the limits of the submandibular triangle. They receive the vessels from the upper and lower lips, nose, cheeks, tongue, palate, palatine tonsils and sublingual and submandibular salivary glands. Their efferent vessels pass to the deep lateral cervical nodes.

The *cervical nodes*, **nodi lymphoidei colli** are subdivided into the anterior and lateral. Each group in turn comprises the superficial nodes situated outside the superficial layer of the cervical fascia and deep nodes that reside deeper.

The *anterior cervical nodes*, **nodi cervicales anteriores** comprise the following groups:

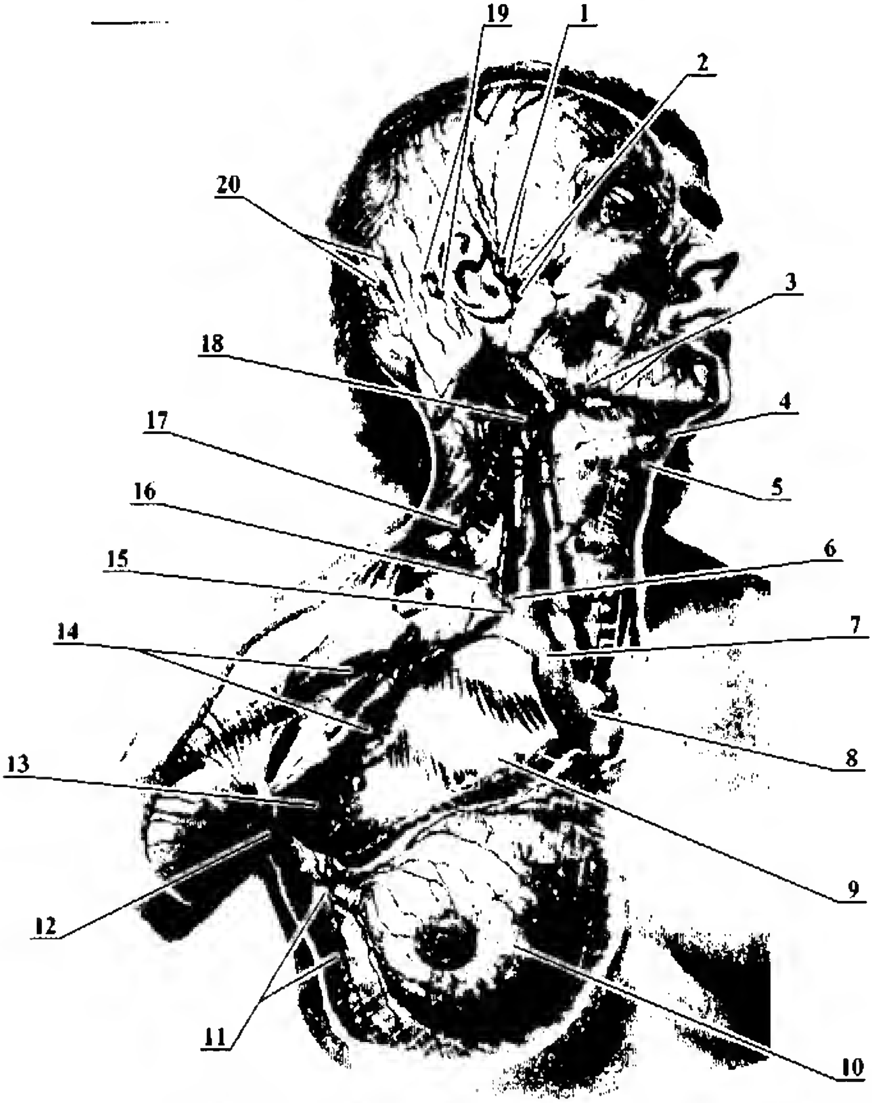


Fig. 122. The lymphatic vessels and nodes of head, neck, axillary area and breast. 1 – nodi lymphoidei parotiidei superficiales; 2 – nodi lymphoidei parotiidei profundi; 3 – nodi lymphoidei submandibulares; 4 – nodi lymphoidei submentales; 5 – nodi lymphoidei cervicales anteriores superficiales; 6 – ductus jugularis dexter; 7 – v. brachiocephalica dextra; 8 – v. cava superior; 9 – m. pectoralis major; 10 – mamma; 11 – nodi lymphoidei paramammarii; 12 – nodi lymphoidei axillares laterales; 13 – nodi lymphoidei axillares centrales; 14 – nodi lymphoidei deltopectorales; 15 – ductus lympfaticus dexter; 16 – nodus juguloomohyoideus; 17 – nodi lymphoidei cervicales laterales superficiales; 18 – nodus lymphoideus jugulodigastricus; 19 – nodi lymphoidei mastoidei; 20 – nodi lymphoidei occipitales.

- the *superficial nodes*, **nodi superficiales** (1-5) group along the anterior jugular vein. They receive afferent lymph vessels from skin and muscles;
- the *deep nodes*, **nodi profundi** (32-83) (the *prelaryngeal nodes*, the *thyroid nodes*, the *pretracheal node*, the *paratracheal nodes* and the *retropharyngeal nodes*). These nodes receive lymph vessels from the respective viscera.

The *lateral cervical nodes*, **nodi cervicales laterales** (11-68) form the groups as follows:

- the *superficial nodes*, **nodi superficiales** group along the external jugular vein. They receive vessels from skin and superficial fascia;
- the *superior deep nodes*, **nodi profundi superiores** are represented with the *jugulodigastric node*, **nodus jugulodigastricus**, the *lateral node*, **nodus lateralis** and the *anterior node*, **nodus anterior**;
- the *inferior deep nodes*, **nodi profundi inferiores** are represented with the *jugulo-omohyoid node*, **nodus juguloomohyoideus**, the *lateral node*, **nodus lateralis**, the *anterior nodes*, **nodi anteriores** and the *retropharyngeal nodes*, **nodi retropharyngeales**. The deep lateral nodes group along the internal jugular vein;
- the *supraclavicular nodes*, **nodi supraclaviculares** (1-3).

The lateral deep nodes drain the lymph nodes of head, the submental and submandibular nodes; they also drain the tongue, pharynx, tonsils, larynx, thyroid gland and the cervical muscles. The efferent vessels from the deep lateral cervical nodes give rise to the left and right jugular trunks that join the respective venous angles.

THE LYMPH NODES AND VESSELS OF THE UPPER LIMB

Lymph from the upper limb flows within the superficial and deep lymph vessels that reach the cubital and axillary lymph nodes (Fig. 123).

The *superficial lymph vessels*, **vasa lymphatica superficiales** form lateral, medial and middle groups that drain skin and subcutaneous fat:

- the *lateral lymph vessels*, **vasa lymphatica laterales** (5-10) drain the fingers 1 through 3 and the lateral aspect of hand, forearm and arm. These vessels run along the cephalic vein and terminate at the axillary nodes;
- the *medial lymph vessels*, **vasa lymphatica laterales** (5-15) drain the fingers 4 through 5 and medial aspect of wrist, forearm and arm. These vessels run along the anteromedial side of the upper limb and terminate at the cubital and axillary nodes;
- the *middle lymph vessels*, **vasa lymphatica medianus** drain the anterior surface of wrist and forearm. The vessels ascend along the median cubital vein to reach the cubital and axillary nodes.

The *deep lymph vessels*, **vasa lymphatica profunda** are responsible for drainage of the muscles, tendons, fasciae, joint capsules, ligaments, peri-

osteum and nerves. These vessels accompany great blood vessels of upper limb. Some vessels reach the cubital nodes yet majority of vessels reach the axillary nodes.

The *lymph nodes of upper limb,* **nodi lymphoidei membri superiores** join into two groups — the cubital and axillary nodes.

The *cubital nodes,* **nodi lymphoidei cubitales** occupy the cubital fossa. They are subdivided into the superficial and deep nodes. The *superficial nodes,* **nodi cubitales superficiales** reside outside the superficial fascia and the *deep nodes,* **nodi cubitales profundi** reside deeper. The cubital nodes receive a certain portion of lymph from hand and forearm. Their efferent vessels pass to the axillary nodes.

The *axillary lymph nodes,* **nodi lymphoidei axillares** are the principal regional lymph nodes of the upper limb. They are embedded into the axillary fat and form 6 groups around the neurovascular bundle: the *medial nodes,* **nodi mediales,** the *lateral nodes,* **nodi laterales** (or the *humeral nodes,* **nodi humerales**), the *central nodes,* **nodi centrales,** the *posterior nodes,* **nodi posteriores** (or the *subscapular nodes,* **nodi subscapulares**), the *anterior nodes,* **nodi anteriores** (or the *pectoral nodes,* **nodi pectorales**). In this region, one can also see the *interpectoral nodes,* **nodi interpectorales** and the *deltopectoral nodes,* **nodi deltopectorales.**

All nodes listed anastomose via the lymph vessels. The axillary nodes drain the upper limbs, breasts, thorac-

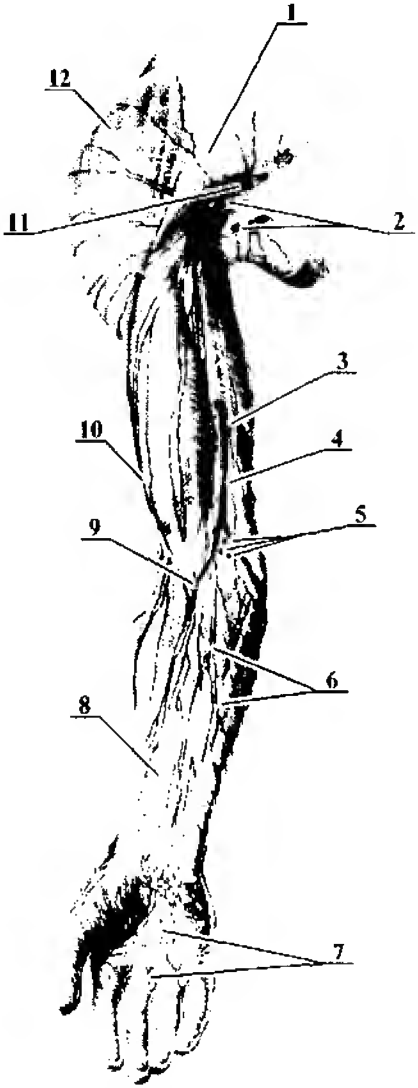


Fig. 123. The lymphatic vessels and nodes of the upper limb. 1 — fascia pectoralis; 2 — nodi lymphoidei axillares; 3 — nodi brachiales; 4 — v. basilica; 5 — nodi lymphoidei cubitales; 6 — vasa lymphatica superficiales antebrachii; 7 — vasa lymphatica superficiales manus; 8 — fascia antebrachii; 9 — v. mediana cubiti; 10 — v. cephalica; 11 — nodi lymphoidei deltopectorales; 12 — fascia deltoidea.

ic walls and back. The efferent vessels given by these nodes give rise to the *subclavian trunks*, **trunci subclavius**. The *right subclavian trunk*, **truncus subclavius dexter** joins the right lymphatic duct or any vein of the right venous angle. The *left subclavian trunk*, **truncus subclavius sinister** joins the cervical part of thoracic duct or any vein of the left venous angle.

THE LYMPH NODES AND VESSELS OF THE LOWER LIMB

The lower limb also features the superficial and deep lymph vessels that form numerous anastomoses. The regional lymph nodes of the lower limb are the popliteal and inguinal nodes (Fig. 124).

The *superficial lymph vessels*, **vasa lymphatica superficiales** of the lower limb arise from the capillary networks of skin and subcutaneous fat. These vessels pass to the popliteal and superficial inguinal nodes. The superficial lymph vessels form the medial, posterior and lateral groups:

- the *medial lymph vessels*, **vasa lymphatica laterales** (8-12) drain the fingers 1 through 3, medial aspect of plantar surface of foot and the medial and posteromedial surfaces of leg. These vessels run along great saphenous vein and terminate at the superficial inguinal nodes;
- the *lateral lymph vessels*, **vasa lymphatica laterales** (1-6) drain the fingers 4 through 5 and the lateral aspect of foot, and leg. These vessels ascend in direction of knee joint and join the medial group slightly below it;

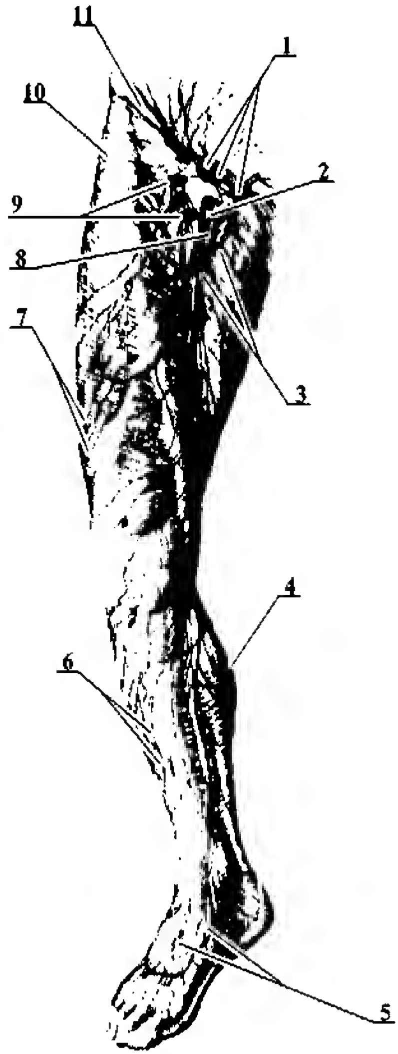


Fig. 124. The lymphatic vessels and nodes of the upper limb. 1 — nodi lymphoidei inguinales superficiales (superomediales); 2 — hiatus saphenus; 3 — nodi lymphoidei inguinales superficiales (inferiores); 4 — fascia cruris; 5 — vasa lymphatica superficiales pedis; 6 — vasa lymphatica superficiales cruris; 7 — vasa lymphatica superficiales femoris; 8 — v. saphena magna; 9 — nodi lymphoidei inguinales superficiales (superolaterales); 10 — fascia lata; 11 — lig. inguinale.

- the *posterior lymph vessels*, **vasa lymphatica posteriores** drain the lateral aspects of the plantar and dorsal surfaces of foot and the calcaneal region. The vessels run along the small saphenous vein and terminate at the popliteal nodes.

The *deep lymph vessels*, **vasa lymphatica profunda** are responsible for drainage of the muscles, joint capsules, synovial bursae, bones and nerves. These vessels accompany great blood vessels of lower limb. These vessels join the popliteal and deep inguinal nodes.

The regional *lymph nodes of lower limb*, **nodi lymphoidei membri inferiores** are represented with the popliteal and inguinal lymph nodes.

The *popliteal nodes*, **nodi lymphoidei poplitei** occupy the popliteal fossa. They are subdivided into the superficial and deep ones:

- the *superficial nodes*, **nodi superficiales** reside outside the popliteal fascia. They receive the posterior and partially lateral lymph vessels;
- the *deep nodes*, **nodi profundi** receive the deep lymph vessels of thigh.

In many cases, only one popliteal node is present.

The efferent vessels given by the popliteal nodes pass to the inguinal lymph nodes.

The *inguinal lymph nodes*, **nodi lymphoidei inguinales** are also subdivided into the superficial and deep ones:

- the *superficial lymph nodes*, **nodi inguinales superficiales** (4-20) reside outside the fascia lata below the inguinal ligament, and around the saphenous opening. They are represented with the *superomedial nodes*, **nodi superomediales**, the *superolateral nodes*, **nodi superolaterales** and the *inferior nodes*, **nodi inferiores**.

The superficial nodes drain the lower limb, skin and fascia of the external genitalia, perineum, buttocks and abdominal wall. The efferent lymph vessels pass to the deep inguinal nodes.

- the *deep inguinal nodes*, **nodi inguinales profundi** reside below the fascia lata within the iliopectineal groove, next to the femoral artery and vein. The upper node (the Pirogov's node) occupies the femoral ring where it adheres to the medial surface of the femoral vein. The deep inguinal nodes drain the deep afferent vessels that come from the lower limb, the external genitalia, the soft tissues of the gluteal region and the anterior abdominal wall. They also receive the efferent vessels given by the superficial inguinal nodes. The efferent vessels of the deep nodes pass the vascular space and terminate at the external iliac nodes.

THE PELVIC LYMPH NODES AND VESSELS

The *pelvic lymph nodes*, **nodi lymphoidei pelvis** are subdivided into the parietal and visceral (Fig. 125).

The *parietal nodes*, **nodi lymphoidei parietalis** neighbor the pelvic blood vessels and pelvic walls. The pa-

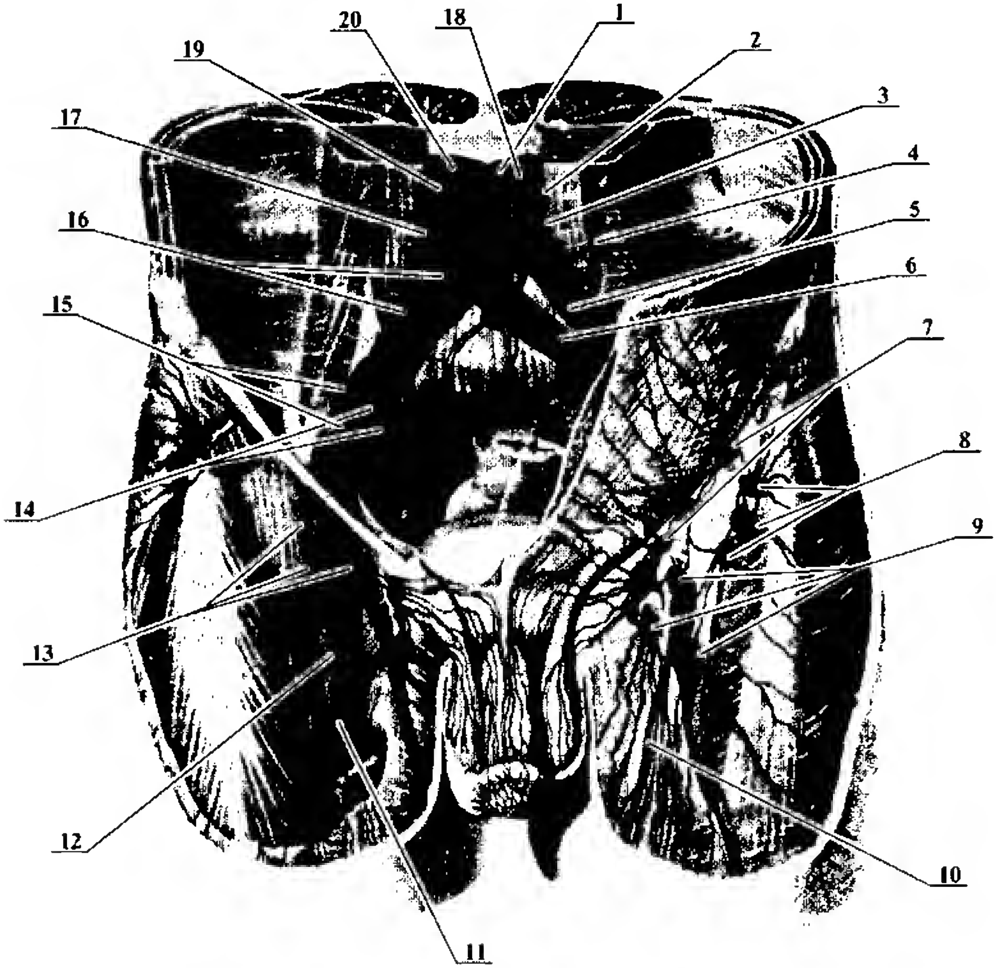


Fig. 125. The pelvic lymph nodes and parietal abdominal lymph nodes. 1 — pars abdominalis aortae; 2 — nodi lymphoidei lumbales sinistri; 3 — nodi lymphoidei aortici laterales; 4 — ureter; 5 — a. iliaca communis; 6 — v. iliaca communis; 7 — nodi lymphoidei inguinales superficiales (superomediales); 8 — nodi lymphoidei inguinales superficiales (superolaterales); 9 — nodi lymphoidei inguinales superficiales (inferiores); 10 — v. saphena magna; 11 — v. femoralis; 12 — a. femoralis; 13 — nodi lymphoidei inguinales profundi; 14 — nodi lymphoidei iliaci interni; 15 — nodi lymphoidei iliaci externi; 16 — nodi lymphoidei iliaci communes; 17 — nodi lymphoidei cavales laterales; 18 — nodi lymphoidei preaortici; 19 — v. cava inferior; 20 — nodi lymphoidei precavales.

rietal nodes are represented with the following nodes:

- the *external iliac nodes,* **nodi iliaci externi** reside along the external iliac artery. They are represented with the *medial nodes,* **nodi mediales**, the *intermediate nodes,* **nodi intermedii**, the *lateral nodes,* **nodi laterales**, the *interiliac nodes,* **nodi interiliaci** and the *obturator node,* **nodi obturatorii.** They receive the efferent vessels given by the deep inguinal nodes;
- the *internal iliac nodes,* **nodi iliaci interni** adhere to the internal iliac artery and the lesser pelvis walls. They are represented with the *gluteal nodes,* **nodi gluteales**, the *superior nodes,* **nodi superiores**, the *inferior nodes,* **nodi inferiores** and the *sacral nodes,* **nodi sacrales.** These nodes receive the vessels from the pelvic walls, urinary bladder, uterus, prostate and rectum; they also receive the efferent vessels from the visceral pelvic nodes. The efferent vessels given by the internal nodes pass to the common iliac nodes;
- the *common iliac nodes,* **nodi iliaci communes** neighbor the common iliac artery. They are represented with the following nodes: the *medial nodes,* **nodi mediales**, the *intermediate nodes,* **nodi intermedii**, the *lateral nodes,* **nodi laterales**, the *subaortic nodes,* **nodi subaortici** and the *promontorial nodes,* **nodi promontorii.** These nodes receive the efferent vessels from the external and internal iliac nodes. The efferent vessels given by the common iliac nodes pass to the lumbar lymph nodes.

The *visceral lymph nodes,* **nodi lymphoidei viscerales** neighbor the pelvic viscera. They are represented with the *paravesical nodes,* **nodi paravesicales**, the *prevesical nodes,* **nodi prevesicales**, the *postvesical nodes,* **nodi retrovesicales** the *para-uterine nodes,* **nodi parauterini**, the *paravaginal nodes,* **nodi paravaginales**, the *pararectal nodes,* **nodi pararectales** and the *anorectal nodes,* **nodi anorectales.**

THE ABDOMINAL LYMPH NODES AND VESSELS

The *abdominal lymph nodes,* **nodi lymphoidei abdominis** are subdivided into the parietal and the visceral nodes.

The parietal lymph nodes

The *parietal lymph nodes,* **nodi lymphoidei parietals** are mainly represented with the *lumbar lymph nodes,* **nodi lymphoidei lumbales** situated next to the abdominal aorta and IVC. They are subdivided into the *left lumbar nodes,* **nodi lumbales sinistri** related to the aorta (the *lateral aortic nodes,* **nodi aortici laterales**, the *pre-aortic nodes,* **nodi preaotrici** and the *postaortic nodes,* **nodi retroaortici**) and the *right lumbar nodes,* **nodi lumbales dextri** (the *lateral caval nodes,* **nodi cavales laterales**, the *precaval nodes,* **nodi percavales** and the *postcaval nodes,* **nodi retrocavales**). Between the aorta and IVC, one can

distinguish the *intermediate lumbar nodes*, **nodi lumbales intermedii**.

The lumbar lymph nodes receive the efferent vessels from the internal and common iliac nodes. Apart from this, they receive vessels that arise immediately from the testes, ovaries, uterine tubes, and the fundus of uterus (that is how the metastases from the uterine and ovarian carcinomas reach the lumbar nodes) i.e. the lumbar lymph nodes drain the lower limbs and the pelvis with related viscera. Apart from this, these nodes receive lymph from the visceral abdominal nodes.

The efferent vessels given by the lumbar nodes merge to form the *left* and *right lumbar trunks*, **trunci lumbales dexter et sinister**.

The group of parietal nodes also includes the following nodes:

- the *inferior epigastric nodes*, **nodi epigastrici inferiores** reside by the anterior abdominal wall next to the blood vessels of the same name. They drain the muscles, skin and parietal peritoneum of the anterior abdominal wall. Some efferent vessels descends to reach the external iliac nodes while other pass to the parasternal nodes;
- the *inferior diaphragmatic nodes*, **nodi phrenici inferiores** reside by the posterior abdominal wall next to the arteries of the same name. They receive the lymph vessels from the diaphragm and posterior portions of both left and right lobes of liver. Their efferent vessels pass to the coeliac, postcaval and intermediate lumbar nodes.

The visceral lymph nodes

The *visceral lymph nodes*, **nodi lymphoidei viscerales** are numerous (several hundred) lymph nodes situated next to the unpaired branches of the abdominal aorta and their divisions. These nodes receive lymph from the abdominal viscera (Fig. 126, 127).

The *coeliac nodes*, **nodi coeliaci** (2-5) reside next to the coeliac trunk and pertaining branches. They receive the efferent lymph vessels given by the nodes of liver, stomach, spleen, duodenum and pancreas. The efferent vessels given by the coeliac nodes pass to the lumbar nodes, lumbar trunks and thoracic duct.

The *right* and *left gastric nodes*, **nodi gastrici dextri et sinistri** (20-25) occupy the lesser curvature of stomach together with the related arteries. They drain the portions of both gastric walls related to the lesser curvature.

The *nodes around cardia*, **anulus lymphaticus cardiae** are 5-10 nodes that receive lymph from the cardial part of stomach, fundus and abdominal part of esophagus.

The *right* and *left gastro-omental nodes*, **nodi gastroomentales dextri et sinistri** occupy the greater curvature of stomach together with the related arteries. They drain the lowermost portions of both gastric walls.

The *pyloric nodes*, **nodi pyloric** reside next to the pyloric part of stomach (the *suprapyloric*, *subpyloric* and *retropyloric nodes* may be distinguishable) and drain it.

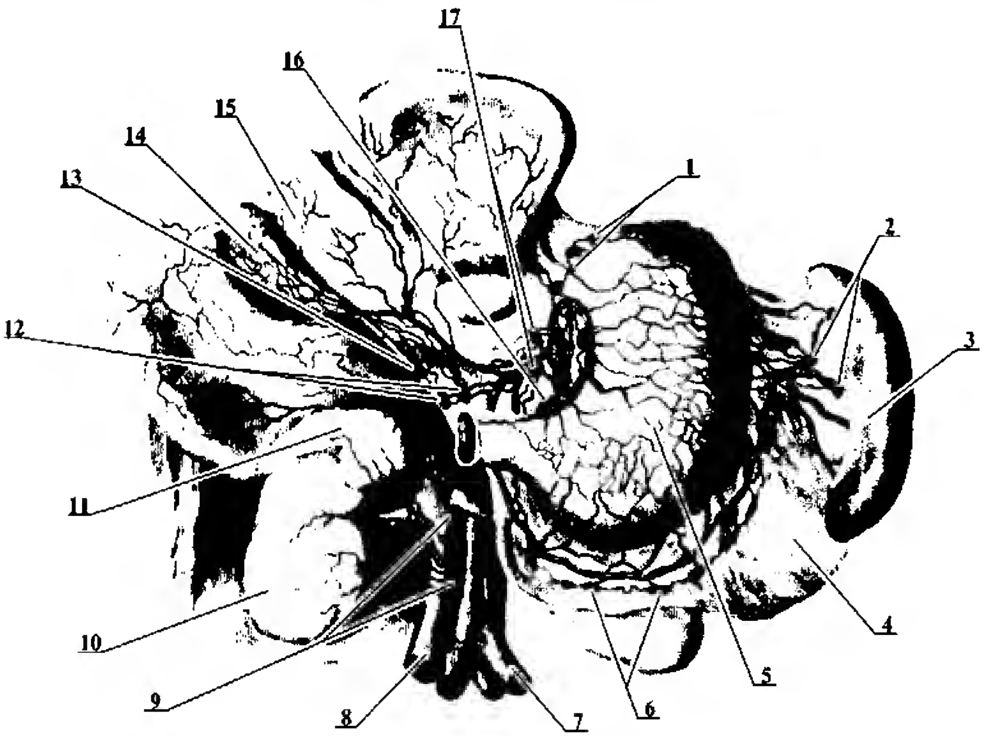


Fig. 126. The visceral abdominal lymph nodes: the gastric nodes related to branches of coeliac trunk. 1 – nodi lymphoidei gastrici dextri et sinistri; 2 – nodi lymphoidei splenici (lienalis); 3 – splen; 4 – omentum majus; 5 – gaster; 6 – nodi lymphoidei gastroomentales dextri; 7 – pars abdominalis aortae; 8 – v. cava inferior; 9 – nodi lymphoidei lumbales; 10 – ren; 11 – glandula suprarenalis; 12 – nodi lymphoidei hepatici; 13 – nodus lymphoideus cysticus; 14 – vesica fellae; 15 – hepar; 16 – nodi lymphoidei pylorici; 17 – nodi lymphoidei coeliaci.

The *superior* and *inferior pancreatic nodes*, **nodi pancreatici superiores et inferiores** reside mainly next to the superior border of pancreas. They are responsible for drainage of the neighboring organ.

The *superior* and *inferior pancreaticoduodenal nodes*, **nodi pancreaticoduodenales superiores et inferiores** (4-6) reside in between the head of pancreas and descending part of duodenum i.e. they are specifically regional nodes for the head of pancreas and duodenum.

The *hepatic nodes*, **nodi hepatici** (4-10) are enfolded into the hepatoduodenal ligament where they neighbor the common hepatic artery and HPV. Two nodes in the group – the *cystic node*, **nodus cysticus** and the *node of anterior border of omental foramen*, **nodus foraminalis** are considered

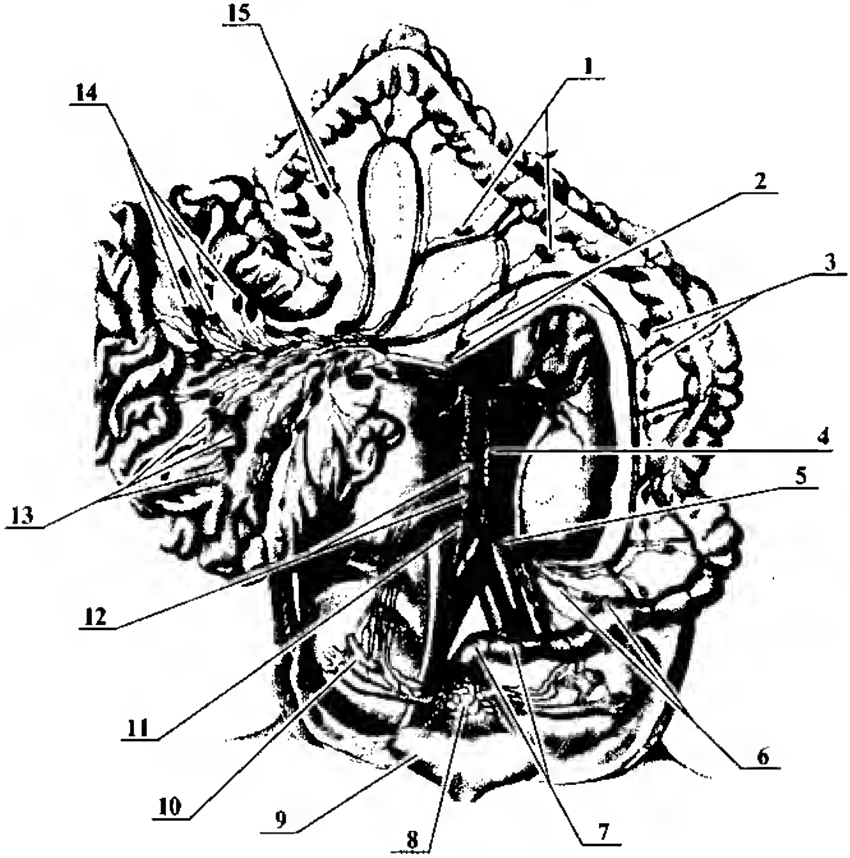


Fig. 127. The visceral abdominal nodes (by Iosifov G.M.). 1 — nodi lymphoidei colici medii; 2 — nodi lymphoidei mesenterici superiores centrales; 3 — nodi lymphoidei colici sinistri; 4 — pars abdominalis aortae; 5 — nodi lymphoidei iliaci communes; 6 — nodi lymphoidei sigmoidei; 7 — nodi lymphoidei rectales superiores; 8 — uterus; 9 — vesica urinaria; 10 — ovarium; 11 — v. cava inferior; 12 — nodi lymphoidei precavales; 13 — nodi lymphoidei juxtaintestinales; 14 — nodi lymphoidei mesenterici superiores; 15 — nodi lymphoidei ileocolici.

separately from the rest. These nodes thus receive lymph from the liver and gallbladder. In some cases, the hepatic lymph nodes join the thoracic duct individually.

The *splenic nodes*, **nodi lienales** are enfolded into the gastrosplenic ligament. They reside within the splenic hilum next to branches of the splenic artery. These nodes receive the efferent vessels from the splenic capsule, fundus of stomach (partially) and left gastro-omental nodes.

The efferent vessels given by the aforesaid visceral nodes pass to the coeliac nodes except for the splenic

nodes that give the vessels to the lumbar nodes and to the lumbar trunks and thoracic duct.

The *superior mesenteric nodes*, **nodi mesenterici superiores** (Fig. 127) constitute the greatest group of the abdominal visceral nodes. The superior mesenteric nodes are arranged into a cascade of three lines. The peripheral line resides next to the mesenteric aspects of both jejunum and ileum, and outside the vascular arcades. Nodes of this line re called the *juxta-intestinal nodes*, **nodi juxtaintestinales**. The nodes of middle line reside next to the main trunk of the superior mesenteric artery and the nodes of central line reside within the root of mesentery. They accompany the superior mesenteric artery up to origination point of the right colic artery. The central group comprises the *central superior mesenteric nodes*, **nodi superiores centrales**, the *ileocolic nodes*, **nodi ileocolici**, the *precaecal nodes*, **nodi precaecales**, the *retrocaecal nodes*, **nodi retrocaecales** and the *appendicular nodes*, **nodi appendicularis**. The latter three groups drain the caecum and the vermiform appendix.

The superior mesenteric nodes anastomose via numerous lymph vessels. Most often, the efferent vessels given by these nodes join the lumbar nodes yet in 25% of occurrences, these vessels merge into several *intestinal trunks*, **trunci intestinales** that join the thoracic duct.

The afferent vessels from the ascending, transverse and descending colons join the *mesocolic nodes*, **nodi mesocolici** that neighbor the respective colic arteries. This group comprises the *paracolic nodes*, **nodi paracolici** and the *right*, *middle* and *left colic nodes*, **nodi colici dextri, medii et sinistri**. This group gives the afferent vessels to the lumbar nodes.

The *inferior mesenteric nodes*, **nodi mesenterici inferiores** are represented with the *sigmoid nodes*, **nodi sigmoidei** and the *superior rectal nodes*, **nodi rectales superiores**. These nodes neighbor the respective arteries. They receive lymph from the sigmoid colon and upper portion of rectum; their efferent vessels pass to the lumbar and superior mesenteric nodes.

THE THORACIC LYMPH NODES AND VESSELS

The thoracic lymph nodes are subdivided into the parietal nodes (they reside by the thoracic walls and pericardium) and visceral nodes (they are related to the thoracic viscera).

The *parietal lymph nodes*, **nodi lymphoidei parietals** are represented with the following nodes:

- the *parasternal nodes*, **nodi parasternales** form two group (10-20 on each side) situated by the posterior surface of anterior thoracic wall next to the internal thoracic arteries and veins. These nodes receive lymph from the soft tissues of the anterior thoracic wall in part from the parietal pleura diaphragm and pericardium; in addition to the regions listed the parasternal nodes drain the diaphragmatic surface of

liver and the breasts. The efferent vessels pass to the right jugular trunk and lymph nodes of the superior mediastinum. The vessels from the left parasternal nodes join the thoracic duct or left jugular trunk, and the mediastinal nodes;

- the *intercostal nodes*, **nodi intercostales** (4-7 on each side) reside within the posterior portions of the intercostal spaces. They drain the posterior thoracic wall in part the parietal pleura. The efferent vessels join the thoracic duct and deep lateral cervical vessels;
- the *superior diaphragmatic nodes*, **nodi phrenici superiores** (10-15) reside on the diaphragm around the pericardium. They are represented with paired (1-4) *lateral pericardial nodes*, **nodi pericardiaci laterales** and *prepericardial nodes*, **nodi prepericardiaci** (1-7). These nodes receive lymph from the diaphragm, pericardium, parietal pleura and diaphragmatic surface of liver. The efferent vessels pass to the parasternal nodes and the visceral mediastinal nodes.

Anterior to the vertebral column, one can distinguish single *prevertebral nodes*, **nodi prevertebrales**.

The *visceral nodes*, **nodi lymphoidei viscerales** drain the thoracic viscera. They adhere to the trachea and main bronchi, brachiocephalic arteries (anteriorly), the SVC and aortic arch, and esophagus. These nodes form the following regional groups (Fig. 128):

- the *bronchopulmonary nodes*, **nodi bronchopulmonales** (15-20) are represented with the *intrapulmonary nodes*, **nodi intrapulmonales** situated within each lung next to forking large bronchi and the *intrinsic* (root) nodes located along the main bronchi. These nodes receive lymph from the lungs, visceral pleura and bronchi. their efferent vessels pass to the superior and inferior tracheobronchial nodes;
- the *tracheobronchial nodes*, **nodi tracheobronchiales** are subdivided into the *inferior tracheobronchial nodes*, **nodi tracheobronchiales inferiores** (5-14) situated below the tracheal bifurcation and *superior tracheobronchial nodes*, **nodi tracheobronchiales superiores** (left group counts 10-30 nodes and the right — 10-25 nodes). The superior nodes reside along lateral aspects of the trachea above the tracheal bifurcation. They receive lymph from the bronchopulmonary and other visceral and parietal nodes. Most of the efferent vessels given join the paratracheal nodes while the rest participate in formation of the bronchomediastinal trunks;
- the *paratracheal nodes*, **nodi lymphoidei paratracheales** (10-20) adhere to both aspects of the trachea. They receive lymph vessels the tracheobronchial nodes and the vessels from the trachea, esophagus, thymus and thyroid gland. The efferent vessels merge into the left and right bronchomediastinal trunks that join the right lymphatic duct and thoracic duct respectively.

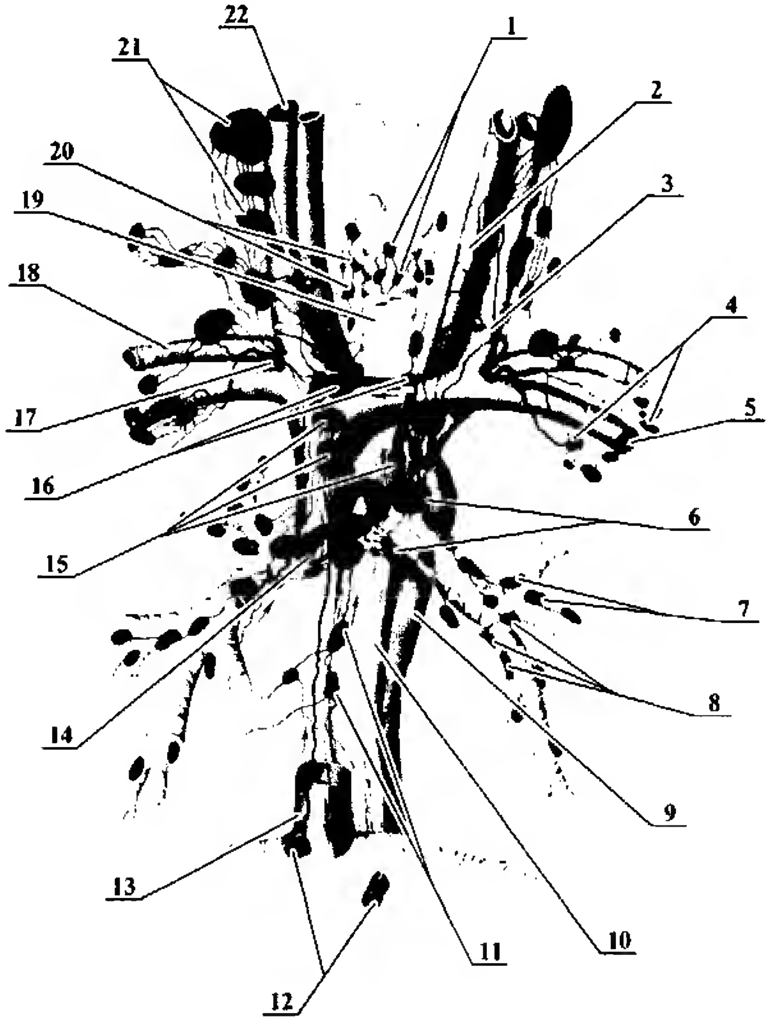


Fig. 128. The mediastinal and cervical lymph nodes (by Zhdanov D.A.). 1 — nodi lymphoidei cervicales anteriores profundi (nodi pretracheales); 2 — a. carotis communis; 3 — ductus thoracicus; 4 — nodi lymphoidei axillares; 5 — v. subclavia; 6 — nodi lymphoidei trachobronchiales superiores; 7 — nodi lymphoidei trachobronchiales inferiores; 8 — nodi lymphoidei bronchopulmonales; 9 — pars thoracica aortae; 10 — oesophagus; 11 — nodi lymphoidei mediastinales posteriores; 12 — nodi lymphoidei phrenici superiores; 13 — v. cava inferior; 14 — v. cava superior; 15 — nodi lymphoidei mediastinales anteriores; 16 — nodi lymphoidei brachiocephalici; 17 — ductus lymphaticus dexter; 18 — a. subclavia; 19 — trachea; 20 — nodi lymphoidei cervicales anteriores profundi (nodi paratracheales); 21 — nodi lymphoidei cervicales laterales profundi; 22 — v. jugularis interna. Movement of lymph is shown with arrows.

The superior mediastinum also houses several groups of nodes that neighbor the brachiocephalic veins, SVC and aortic arch with related branches: the *brachiocephalic nodes*, **nodi brachiocephalici**, the *node of arch of azygos vein*, **nodus arcus venae azygos** and the *node of ligamentum arteriosum*, **nodus ligamenti arteriosi** (it neighbors the ligamentum arteriosum). These nodes receive efferent vessels from the heart, pericardium, thymus, bronchopulmonary and tracheobronchial nodes. The efferent vessels given by these nodes may join the right lymphatic duct, the thoracic duct or the veins related to the venous angles.

The mediastinal fat around the esophagus and thoracic aorta contains about 5-10 *juxta-esophageal nodes*, **nodi juxtaesophageales** that collect lymph from the esophagus and posterior mediastinum. Their efferent vessels join the thoracic duct and inferior tracheobronchial nodes.

THE LYMPH NODES OF BREAST

Incidence of breast cancer exhibits rapid increase during recent years. In view of this, lymph drainage of breasts requires thorough studying.

The efferent lymph vessels from the breasts take different routes radiating to neighboring regional nodes (Fig. 122). The **superolateral sector of breast** gives the vessels to the central, medial and apical axillary nodes, and to the lower deep lateral cervical nodes and parasternal nodes. The **inferolateral sector of breast** drains lymph to the medial and central axillary nodes, and to the parasternal nodes, the **superomedial sector** drains lymph to the parasternal, upper mediastinal and axillary nodes and the **inferomedial sector** drains lymph to the parasternal and axillary nodes. The **deep portions of breast** drain lymph to the intercostal nodes.

THE LYMPHOID ORGANS

The lymphoid organs possess certain developmental and structural features:

1. Parenchyme of all lymphoid organs is made up of lymphoid tissue, which comprises T- and B-lymphocytes and macrophages.

2. All primordia of the lymphoid organs appear at early stages of development (e.g. the red bone marrow and thymus appear at the 4^{th} or 5^{th} week, the spleen appears at the 5^{th} or 6^{th} week, the lymph nodes – at the 7^{th} or 8^{th} week, the palatine and pharyngeal tonsils – between the 9^{th} and 14^{th} weeks, the intestinal aggregated lymphoid nodules and appendicular lymphoid nodules – between the 14^{th} and 16^{th} weeks, the mucosal solitary lymphoid nodules – at the 16^{th} week, the

lingual tonsil – at the 24^{th} week and the tubal tonsils – at the 28^{th} week).

3. All lymphoid organs in newborns are fully developed and ready to perform the protective function. However, newborn's immune system is not capable of normal immune response and requires maternal support provided by breastfeeding.

4. All lymphoid organs reach maximum development (i.e. size, weight and number) in childhood and teen years.

5. All lymphoid organs undergo early age-related involution, which starts in teen years. The lymphoid tissue becomes substituted with fat and connective tissue (thymus is the best example of such involution).

6. The primary lymphoid organs occupy well-protected areas (red bone marrow resides within the bones, the thymus occupies the superior mediastinum). The lymphoid tissue has a specific microenvironment – myeloid tissue for the red bone marrow and epithelioreticulocytes for the thymus.

7. The secondary lymphoid organs occupy the areas of possible pathogens invasion or guard possible expansion routes. For instance, the pharyngeal lymphoid ring encircles the pharyngeal inlet next to openings of the nasal and oral cavities. Mucosa of the alimentary and respiratory systems and the urine voiding passages contains numerous solitary and aggregated lymphoid nodules. The lymph nodes interrupt lymph flow from the organs and tissues. The spleen that passes blood from arteries to veins is the only blood control organ.

8. At early developmental stages, lymphoid tissue exhibits continuous differentiation of diffuse lymphoid cells into lymphoid nodules. The nodules feature germinative centers responsible for antigen dependent proliferation and differentiation of T- and B-lymphocytes. Antigen influence leads to proliferation of lymphoid nodules.

THE PRIMARY LYMPHOID ORGANS

The red bone marrow

The *bone marrow*, **medulla ossium** is the hemopoietic and lymphoid organ (analogue bursa of Fabricius in birds) responsible for antigen independent proliferation and differentiation of B-lymphocytes produced by the stem cells. The bone marrow is subdivided into the *red bone marrow*, **medulla ossium rubra** situated within the cancellous bone cells of flat, short and long bones (in the long bones, the red bone marrow occupies the epiphyses) and the *yellow bone marrow*, **medulla ossium flava** situated within the diaphyses of long bones. In adult individual, the bone marrow weighs about 2.5-3 kilograms; half of this weight comes at the red bone marrow. Stroma of the red bone marrow is formed of reticular cells and fibers; the stem cells as the progenitors of all blood cells are also present there.

The red bone marrow appears as long strands that enfold the arterioles. Great discontinuous capillaries called the sinusoids separate the strands.

Hemopoiesis in embryo starts at the 19th day of development within the hemopoietic islets of yolk sac. Hemopoiesis here lasts up to the 4th month of development and then passes to the liver. In liver, hemopoiesis becomes evident at the 6th week and in the spleen — at the 3rd month (here it lasts until birth).

The red bone marrow originates by the end of the 2nd month of development; the pertaining vessels (and sinusoids) appear at the 12th week of embryo's life. The reticular tissue enfolds the vessels and the hemopoietic islets appear and begin functioning. Since this time, the red bone marrow acquires full functionality. Beginning from the 20th week of development, the red bone marrow exhibits intensive growth and enters the epiphyses and diaphysial cavities.

In newborns, all bones are filled with red bone marrow. First fat cells appear in 1-6 month after birth. Beginning from 4-5 years of life, one can see active replacement of red bone marrow with the yellow bone marrow (rounded cells with cytoplasmic fat deposits). In adults, diaphyseal cavities contain only yellow bone marrow.

The thymus

The *thymus* (Lat. Id.) is the primary lymphoid organ responsible for antigen independent proliferation and differentiation of T-lymphocytes. From thymus, the T-lymphocytes carried by blood low reach the secondary

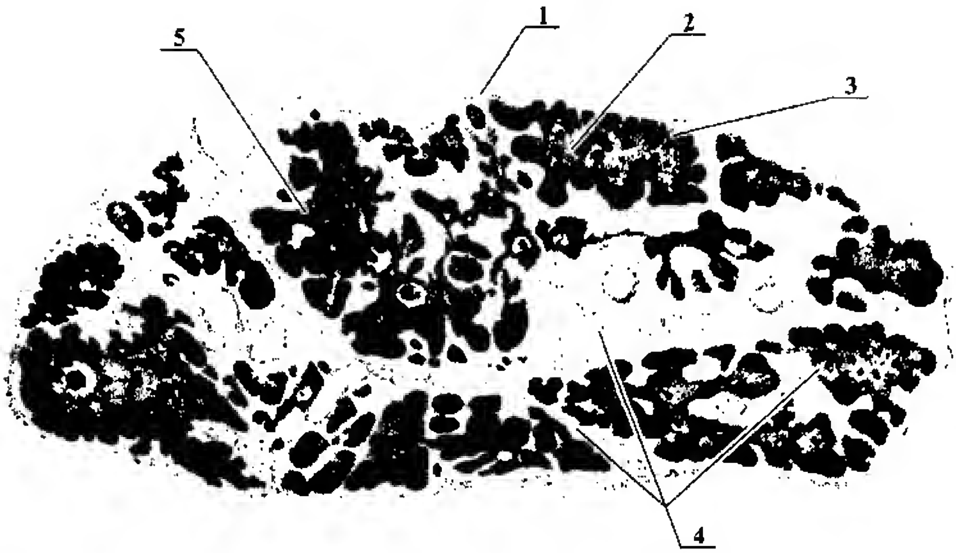


Fig. 129. Internal structure thymus. 1 — capsula thymi; 2 — medulla thymi; 3 — cortex thymi; 4 — septa interlobularia; 5 — corpuscula thymi.

lymphoid organs where they occupy thymus dependent zones (T-zones). Apart from this, the thymus is an endocrine gland (See details in Volume 2 of present edition, page 237).

The thymus is covered with a thin connective tissue capsule, which gives numerous thin septa into parenchyme. The septa separate lobules that range from 1 to 10 mm in size (Fig. 129).

The peripheral portion of each lobule is called the cortex and the central portion – the medulla.

The cortex contains compacted small and middle surrounded by the macrophages. The cortex receives progenitors of the T-lymphocytes borne in red bone marrow. Here they proliferate under effect of thymosin. The subcapsular area contains numerous large (12-13 μm) T-lymphocytes. The lymphoblasts divide and migrate to the medulla where they end differentiation and appear ever since as small cells (6-7μm).

The medulla of thymic lobule is formed of small, middle and large T-lymphocytes. Another specific feature of the medulla constitutes presence of special concentric layers of epithelial cells called the thymic bodies (the Hassal's bodies). Their function is still unknown.

The microcirculatory network of thymus features hematothymic barrier that protects the thymic parenchyme against circulating antigens.

The thymus originates at the 4th week of development from the epithelial cells of the III and IV branchial arches on each side. The primordia grow in caudal direction and join the mesenchyme. The epithelial cells give rise to the epithelioreticulocytes. At the 2nd month of development, the thymus receives the blood capillaries that bring the stem cells – the lymphocytes progenitors. These cells occupy the peripheral area of the primordium; they divide, differentiate into small lymphocytes and migrate deeper into the parenchyme. Divisions of thymus (lobules, cortex and medulla) become evident at the 3rd month of development. Maximum development of thymus comes at 10-15 years of life. At that period, the thymus weighs about 375 grams and sizes about 7.5-16 cm in length. With aging, the thymus undergoes involution and in elderly individuals, it weighs about 13-15 grams. Ninety per cent of thymus weight comes at fat and connective tissue.

Persistent thymus causes severe disease called the *status lymphaticus*. The pathology is manifested mainly as low resistance to infections and intoxication; the organism also becomes susceptible to malignancies. Stress, traumas, intoxications, infections etc cause so-called accidental involution of thymus. In this case, majority of lymphocytes die and the rest migrate to the secondary lymphoid organs; the epithelioreticulocytes undergo intensive proliferation, which makes cortex and medulla indistinguishable. These changes result from protective reaction of the organism.

THE SECONDARY LYMPHOID ORGANS

The lymph nodes

The *lymph node*, **nodus lymphoideus (nodus lymphaticus, lymphonodus)**

The lymph nodes are the secondary lymphoid organs that interrupt lymph flow on the way from the organs to the trunks and ducts. The lymph nodes are the biological filters that inactivate antigens and generate targeting immune response.

The lymph nodes feature variety of shapes but most commonly they appear as bean-shaped bodies, which range in size from 0.5 to 50 mm and even more. The lymph nodes are embedded into loose connective tissue; they may be single or clustered (a cluster may comprise up to several dozens of nodes). The nodes related to a certain body area are called the regional lymph nodes. The regional nodes are subdivided into the parietal, visceral and mixed nodes. The parietal nodes receive the afferent vessels from skin, subcutaneous fat and all components of locomotor apparatus; the visceral nodes drain the respective viscera and the mixed nodes drain both body and viscera.

The lymph node (Fig. 130) is covered with connective tissue *capsule*, **capsula**, which gives *trabeculae* (Lat. Id.) into the node parenchyme. The trabeculae are subdivided into the cortical and medullary. The trabeculae form a kind of framework; they also pass the blood vessels and nerves. Spaces between the trabeculae are filled with stroma represented with reticular cells and fibers. This three-dimensional network holds the lymphoid parenchyme, which consists of lymphoid cells, macrophages and other cells.

The convex portion of the node receives 4-8 or even more *afferent lymph vessels*, **vasa afferentia**, which open into the *marginal (subcapsular) sinus*, **sinus marginalis**. On the opposite side, one can see a small excavation – the *hilum* (Lat. Id.), which passes blood vessels, nerves and the *efferent lymph vessels*, **vasa efferentia**. The efferent vessels pass to next node or join the collector.

The parenchyme of the node consists of the *cortex* (Lat. Id.), which is the peripheral portion adherent to capsule and the *medulla* (Lat. Id.), which is its central portion situated closer to the hilum. The parenchyme comprises the structural components related to T- and B-dependent zones.

The parenchyme of the node also has numerous narrow canals called the *intermediate lymphoid sinuses*, **sinus intermedius lymphonodi**, which lead lymph from the marginal sinus to the hilar sinus. All sinuses are invested with endothelium-like littoral cells. The cortex passes the *cortical intermediate sinuses*, **sinus intermedius corticales**, which neighbor the cortical trabecula on one side and the parenchyme on another. The medulla contains the *medullary intermediate sinuses*, **sinus intermedius med-**

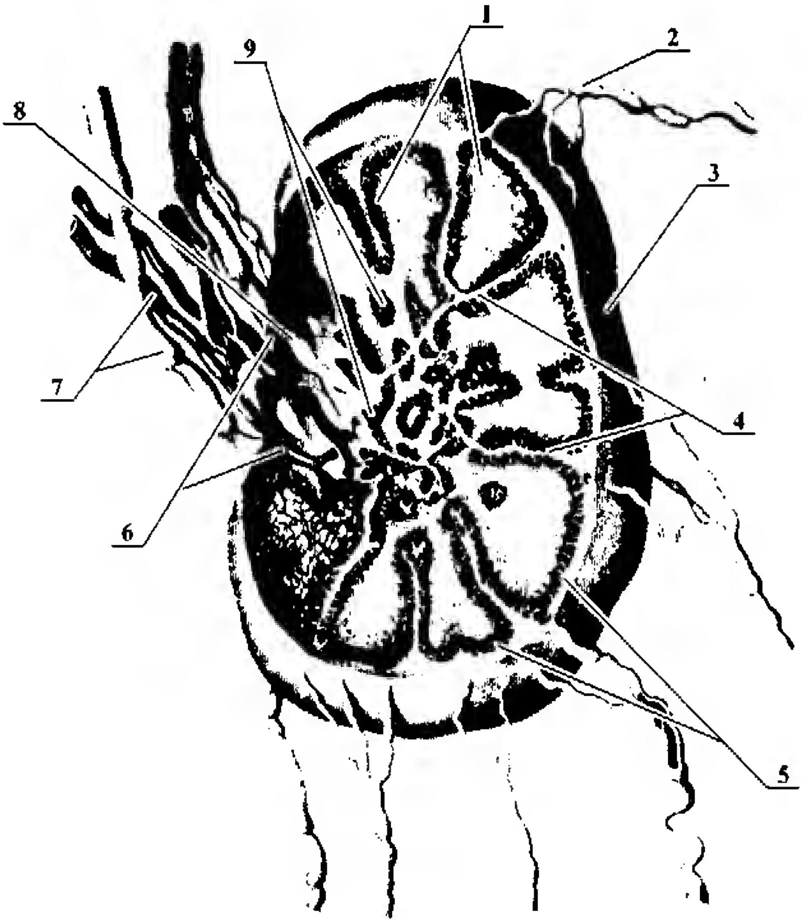


Fig. 130. Structure of lymph node. 1 – cortex lymphonodi; 2 – vas lymphaticum afferentia; 3 – capsula; 4 – trabeculae; 5 – sinus marginalis; 6 – hilum lymphonodi; 7 – vasa lymphatica efferentia; 8 – sinus terminalis; 9 – medulla lymphonodi.

ullares. The medullary sinuses feature variety of shapes; some sinuses reside between the medullary strands while other sinuses enfold the medullary trabeculae and the medullary strands stay outside.

The peripheral portion of the cortex contains numerous *lymphoid nodules,* **noduli lymphoidei** sized 0.5-1 mm. These nodules are aggregated lymphocytes mainly of B-lineage. These structures therefore are called

the B-dependent zones. The nodules are subdivided into the primary lymphoid nodules, which have no light center (they are scarce) and the secondary lymphoid nodules with featured light (germinative) center. The peripheral area of the lymphoid nodule is called the crown or mantle. The lymphoid cells, macrophages and other cells continuously migrate through the crown. Number of secondary nodules increases after antigen influence.

The portion of cortex situated between the lymphoid nodules and marginal sinus is called the subcapsular or marginal zone. Here one can distinguish small and middle lymphocytes. Deeper layer of cortex that neighbor medulla is called the paracortical zone. This zone is T-dependent because it contains small T-lymphocytes. The paracortical zone features numerous postcapillary venules invested with high endothelium. These venules are responsible for recirculation of lymphocytes.

The medullary parenchyme is represented with various *medullary strands*, **chordae medullares**. The strands contain mostly B-lymphocytes. In part, one can distinguish mature plasmatic cells (B-effectors) that produce antigens and macrophages (they are obligatory cells in this zone). The medullary strands thus belong to B-dependent zone.

The lymphoid cells continuously migrate, proliferate and differentiate within the structural components of the lymphatic node. A considerable share of lymphocytes proceeds to other lymph nodes or to the lymphatic trunks and ducts, which open into the veins. Further, the lymphocytes return to the secondary lymphoid organs and tissues.

The lymph nodes originate at the 5th week of development from the mesenchyme that enfolds newly formed blood and lymph vessels. The mesenchyme enters the vessel lumen and its cells differentiate into node parenchyme. The lumen of captured segment transforms into the marginal sinus and its branches give rise to the marginal sinuses. Beginning from the 19th week of development, the demarcation line between the cortex and medulla becomes apparent. The lymphoid nodules appear somewhat later. Germinative centers appear shortly before birth. Formation of lymphoid nodules continues throughout the entire prenatal developmental period and even after birth. The main formation processes commonly end by 10-12 years of life. Involution of the lymphoid organs begins becomes apparent after puberty. With aging, number of lymph nodes decreases.

The spleen

The *spleen*, **splen** or **lien** is a secondary lymphoid organ that provides immune control on blood running from aorta to the HPV system. The spleen destroys waste RBC and other blood cells, and inactivates the antigens. Apart from this, the spleen is responsible for antigen dependent proliferation and differentiation of T- and B-lymphocytes. The spleen

resides within the upper portion of the abdominopelvic cavity (with the respect to the left hypochondriac region) at the level of the ribs 9 through 11. With the respect to peritoneal cavity, the spleen occupies the splenic recess related to the superior level.

In adults, the spleen weighs about 150-200 grams; it appears as concave-convex body 10-14 cm long, 6-10 cm wide and 3-4 cm thick (Fig. 130).

The spleen has the *diaphragmatic* and *visceral surfaces*, **facies diaphragmatica et visceralis**, the *superior* and *inferior borders*, **margo superior et inferior** and the *anterior* and *posterior extremities*, **extremitas anterior et posterior**. The visceral surface contains the *renal*, *gastric* and *colic impressions*, which are in contact with the respective organs. On the visceral surface, one can distinguish an elongated excavation called the *splenic hilum*, **hilum splenicum (hilum lienale)**, which passes the vessels and nerves.

The spleen is covered with peritoneum almost from all sides except for the hilum. The peritoneum forms the ligaments that suspend the organ. The ligaments are the *gastrosplenic ligament*, **ligamentum gastrospleni-**

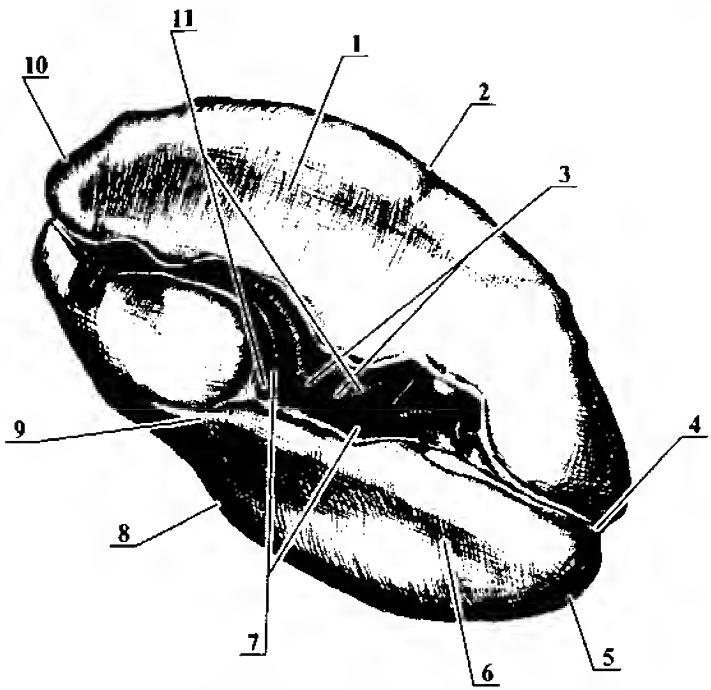


Fig. 131. Spleen (the visceral surface). 1 — facies gastrica; 2 — margo superior; 3 — a. splenica; 4 — lig. gastrolienale; 5 — extremitas anterior; 6 — facies colica; 7 — v. splenica; 8 — margo inferior; 9 — facies renalis; 10 — extremitas posterior; 11 — hilum lienis (splenicum).

cum (gastrolienale), which runs from the hilum to the greater curvature of stomach, the *phrenicosplenic ligament*, **ligamentum phrenicosplenicum** the *splenocolic ligament*, **ligamentum splenocolicum** and the *splenorenal ligament*, **ligamentum splenorenale**.

The peritoneum adheres to the *fibrous capsule*, **capsula (tunica fibrosa)**. The capsule gives the *splenic trabeculae*, **trabeculae splenicae** into splenic parenchyme (Fig. 132). Apart from the trabeculae, the fibrous framework of spleen forms stroma, which consists of the reticular cells and fibers. The stroma supports the splenic parenchyme – the *splenic pulp*, **pulpa splenica**. The pulp is subdivided into the *red pulp*, **pulpa rubra** and the *white pulp*, **pulpa alba**.

The red pulp is dominating portion of splenic parenchyme (its share is about 75-80% of the entire spleen weight). It is represented with formed blood elements that occupy the stroma or splenic sinuses. The portions of red pulp situated between the venous sinuses are called the *splenic cords*, **chordae lienis**. In the cords, B-lymphocytes and monocytes transform into plasmatic cells and macrophages respectively. The splenic macrophages destroy old or damaged RBC and platelets.

The white pulp constitutes 20-25% of spleen mass. It appears as islets disseminated around the red pulp. The white pulp is the lymphoid tissue formed of lymphocytes, dendrite cells and interdigitating cells. The white pulp functions as the secondary lymphoid organ. The white pulp consists of the lymphoid nodules and periarterial lymphoid sheaths.

The *splenic lymphoid nodules*, **noduli lymphoidei splenici** (0.3-0.5 mm in diameter) comprise four zones – the periarterial, mantle and marginal zones and the light (germinative) center. The nodules are responsible for proliferation and differentiation of lymphocytes. The periarterial zone comprises aggregated T-lymphocytes and macrophages that enfold the central artery (it pierces the nodule eccentrically). This area is analogue paracortical zone of lymph nodes. Darker mantle zone that surrounds the light center comprises small B-lymphocytes, small number of lymphocytes, plasmatic cells and macrophages. The marginal zone neighbors the red pulp; it is surrounded by sinusoid capillaries. This zone contains the lymphocytes and macrophages. Upon maturation, the lymphocytes migrate from the light center to the mantle and marginal zones from where they pass to the blood flow.

The *lymphoid periarterial sheaths*, **vaginae periarteriales lymphoidei** are elongated aggregations of lymphocytes that enfold the arteries of white pulp; they are continuous with the lymphoid nodules. The central portion of the sheath comprises B-lymphocytes and the peripheral – T-lymphocytes.

The spleen features a special circulatory network that ensures proper functioning of the organ. The splenic artery gives off several branches yet outside the hilum. These branches enter the splenic hilum and give off the

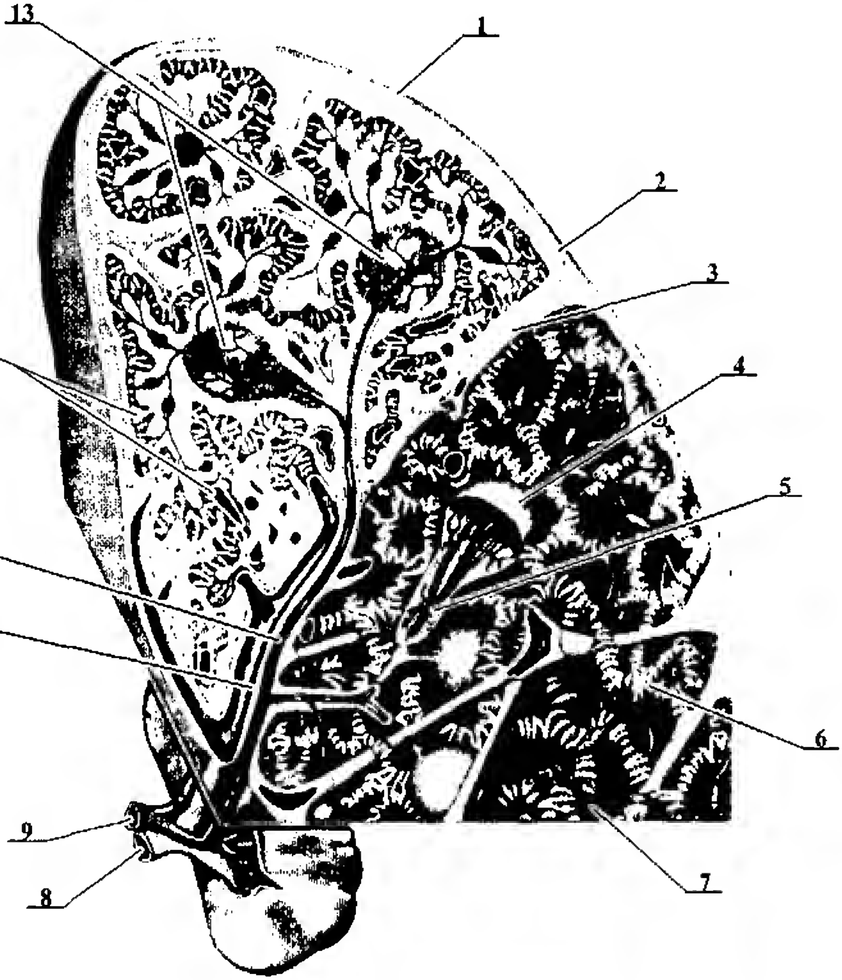


Fig. 132. Spleen (internal structure). 1 — tunica serosa; 2 — capsula (tunica fibrosa); 3 — trabeculae splenicae; 4, 13 — noduli lymphoidei splenici (pulpa lienis alba); 5 — a. centralis; 6 — sinus splenicus; 7 — pulpa lienis rubra; 8 — v. splenica; 9 — a. splenica; 10 — a. trabecularis; 11 — v. trabecularis; 12 — sinus venosi splenici.

segmental arteries, which in turn give the trabecular arteries. The trabecular arteries pass the splenic trabeculae and eventually enter splenic parenchyme. The trabecular arteries feature well-developed muscular layer especially the spiral layer. The arteries related to pulp are the pulpar arteries (0.2 mm in diameter). They run within the periarterial lymphoid sheaths. These arteries pass the lymphoid nodules where they are called the central arteries. The central arteries lack the internal elastic membrane; their endothelial investment is thin. On leaving the nodule, the central artery gives 2-6 *penicilli* to the red pulp. The penicilli are enfolded into ellipsoid muffs – the aggregations of macrophages, lymphocytes and reticular cells. Because of contents and shape these muffs are also called the macrophageal-lymphoid or ellipsoid muffs. The pertaining arterioles are also called the ellipsoid arterioles. The reticular cells and fibers of these structures work as sphincters. Wall of such arteriole is similar to that of a typical capillary. The penicilli are continuous with the capillaries, which open into the *splenic sinuses*, **sinus splenicus**. Some capillaries open directly to the red pulp forming thus the open blood flow system. The venous sinuses also perform depot function. The sinuses are continuous with the veins of red pulp. The junction points contain venous sphincters formed of smooth muscular cells. The sphincters regulate blood flow within the spleen. The veins of red pulp are continuous with the trabecular veins that merge into splenic vein. The splenic vein carries blood to the HPV.

The spleen originates at the 5th or 6th week of development from mesenchymal aggregation situated within the dorsal mesentery. Later, within this aggregation one can distinguish several fissures – future splenic vessels with neighboring pulp cells. The venous sinuses and other vasculature segments develop between the 2nd and 4th months of development. At this time, the capsule gives the projections, which form the trabeculae. Next to the venous sinuses, one can distinguish hemopoietic islets. At the 3rd month of development, all components of white pulp, in part the germinative centers become apparent. The red pulp becomes evident at the 6th month. Beginning from the 6th month, the myeloid hemopoiesis slows down and almost ceases before birth. Intensity of lymphocytes production on the contrary increases. In newborn, the spleen weighs about 9.5 grams; white pulp share constitutes 5-10% of total weight. Red pulp share remains relatively stable throughout the life and ranges between 82 and 85%. White pulp share decreases with aging. After 50 years of life, its share does not exceed 6.5% of total weight.

The lymphoid structures of the alimentary, respiratory and genitourinary systems

The tonsils

The *tonsils*, **tonsillae** are the secondary lymphoid organs that reside

in the fauces, root of tongue and nasopharynx. They form the *pharyngeal lymphoid ring*, **anulus lymphoideus pharyngis**, which encircles the pharyngeal inlet. The structural functional unit of the tonsil is the *lymphoid nodule*, **nodulus lymphoideus**, which is similar to nodule of the lymph node.

The *lingual tonsil*, **tonsilla lingualis** occupies the lamina propria of the mucosa of the root of tongue. It consists of numerous (80-90) lymphoid nodules 1-4 mm of diameter. The tonsil is of ovoid shape; it reaches maximum length (up to 25 mm) in mid-teen age (in about 14). The mucosa above the tonsil features the excavations called crypts. The crypts are invested with the squamous epithelium infiltrated with the lymphocytes.

The lingual tonsil originates at the 6th month of development and the nodules become apparent at the 8th month. The germinative centers arise only after birth and develop throughout the first month of life. Initially, number of lymphoid nodules continuously increases: in neonates – up to 66, in early childhood – up to 85 and in teenagers – up to 90 nodules. Diameter of the nodules in this period reaches 2-4 mm. After puberty, number of lymphoid nodules gradually decreases.

The *palatine tonsil*, **tonsilla palatina** is a paired elongated body that occupies the *tonsillar fossa* (it is delimited by the palatoglossal and palatopharyngeal arches). The lateral aspect of the tonsil adheres to the fibrous plate of pharynx. The plate gives thin septa that separate the lobules of tonsil. The medial surface is covered with the squamous epithelium; in that area, one can distinguish the *tonsillar pits*, **fossulae tonsillares**. Somewhat deeper one can see the *tonsillar crypts*, **cryptae tonsillares** that open into the pits. The parenchyme of the tonsil comprises numerous lymphoid nodules; the largest ones have well distinguishable germinative centers. The lymphoid tissue resides between the nodules.

The palatine tonsils originate at the 12th week of development from the mesenchymal aggregation situated below the second pharyngeal cleft. At the 5th month, the lymphoid tissue receives the epithelial cords that further give rise to the crypts. Number of lymphoid nodules continuously increases; the solitary nodes appear shortly before birth yet the germinative centers appear only after birth. During the first year of life, the palatine tonsil doubles in size – in that period, it is 15 mm long and 12 mm wide. Maximum size is observed in 8-13 year old children; then it is 28 mm long and 22 mm wide. Beginning from 22-30 years of life, the lymphoid tissue undergoes age-related involution.

The *pharyngeal (adenoid) tonsil*, **tonsilla pharyngea (adenoidea)** resides under the mucosa of the nasopharynx in the area where the vault and posterior wall of pharynx meet. Here, the mucosa covered with simple ciliary epithelium forms 4 to 6 transverse and oblique folds. The parenchyme of the tonsil comprises the lymphoid tissue and lymphoid nod-

ules. In children, the tonsils sometimes enlarge and the folds may even cover the choanae, which results in labored nasal breathing.

The pharyngeal tonsil arises at the 3rd month of development within developing pharyngeal mucosa. In newborns, the tonsil is well distinguishable; it is 5-7 mm long and 5-6 mm wide. During the first year of life, the tonsil exhibits rapid growth; the lymphoid nodules appear in the same period. By the end of the first year of life, the tonsil is 12 mm long and 6-10 mm wide. The greatest size of the tonsil is observed in the period from8 to 20 years of life – it is 13-21 mm long and 10-15 mm wide. Further, the tonsil undergoes age-related involution.

The *tubal tonsil*, **tonsilla tubaria**, also paired, it resides within the pharyngeal mucosa next to the pharyngeal opening of auditory tube. Here, the mucosa is invested with the simple ciliary epithelium and features the *tonsillar crypts*, **cryptae tosillares**.

The tubal tonsil arises at the 7th month of development within the mucosa of the respective area. The lymphoid tissue appears during prenatal development while the lymphoid nodules and germinative centers appear during the first year of life. In newborns, the tonsil sizes about 7.5 mm; maximum size is observed in 4-7 year old children.

The *lymphoid nodules*, **noduli lymphoidei**

The mucosa and submucosa of the alimentary system (the pharynx, esophagus, stomach, small and large intestines and gallbladder), respiratory system (the larynx, trachea and large bronchi) and voiding passages (ureters, urinary bladder and urethra) contains numerous (up to 45 nodules per 1 sq. cm of mucosa) lymphoid nodules that 'monitor' antigen status of the respective passages. Apart from the nodules, these organs also contain the lymphoid tissue.

The lymphoid nodules are subdivided into the *solitary lymphoid nodules*, **noduli lymphoidei solitarii** and the *aggregated lymphoid nodules*, **noduli lymphoidei aggregati**.

The *solitary lymphoid nodules*, **noduli lymphoidei solitarii** are the rounded or oblong bodies sized about 1.5-2 mm. Stroma of the nodules comprises the reticular cells and fibers that hold T- and B-lymphocytes. In childhood and adolescent years, majority of nodules feature germinative centers with numerous lymphoblasts (i.e. the progenitors of lymphocytes), macrophages and plasmatic cells, which points at intensive lymphopoiesis. The germinative center is surrounded by darker mantle, which comprises compacted small lymphocytes. Blood capillaries form network around each nodule. Some capacitated cells migrate to blood flow via the walls of postcapillary venules; other cells pass to the related organ.

The *aggregated lymph nodules*, **noduli lymphoidei aggregati** comprise 5-150 packed solitary lymph nodules and diffuse lymphoid tissue. The small intestine and especially ileum feature numerous aggregated

lymphoid nodules called the *lymphoid* or *Peyer's patches.* A typical patch is 0.2-15 cm long and 0.2-1.5 cm wide. The mucosa above the patch is elevated and the patch is well visible. The patches usually reside opposite to the mesenteric aspect of the intestine.

The lymphoid nodules and patches originate within the respective organs at the 4th month of development. The primordia appear as colonies of myeloid cells; by the 6th month, the nodules and patches are fully developed. In newborns, the patches are flat and only 2 cm long however the nodules already have the active germinative centers. In 10-15 year old children, number of both solitary and aggregated nodules increases twofold as compared to newborns. Beginning from adolescent years, number of nodules gradually decreases and in 50-60 year old individuals, the nodules lack germinative centers. In elderly individuals, only diffuse lymphoid tissue persists.

The *appendicular aggregated lymphoid nodules,* **noduli lymphoidei aggregati appendicis vermiformis** reside within mucosa and submucosa of the vermiform appendix. In children and teenagers, number of these nodules reaches maximum value – up to 550; their diameter ranges between 0.2 and 1.2 mm. Most of the nodules in this period contain germinative centers with lymphoblasts, macrophages and plasmatic cells.

The appendicular lymph nodules become apparent at the 4th month of development, first within the mucosa and then within the submucosa. The germinative centers appear either shortly before or right after birth. Diameter of nodules in this period already reaches mature 0.2-1.5 mm; number of nodules is about 150-200. Beginning from adolescence, number of nodules gradually decreases. Only few nodules remain in individuals above 60.

COMPARATIVE ANATOMY OF LYMPHOID SYSTEM

The lymphoid system is relatively new with the respect to cardiovascular system. In invertebrates and inferior vertebrates, the lymph nodes and vessels are absent. Cyclostomes and inferior fish feature joint hemolymphatic system. Only superior fish develop separate lymph vessels.

The inferior vertebrates (fish, amphibians and reptiles) feature wide slit-like extensions of the lymph vessels – the lymphatic recesses situated under skin, within the intestinal wall, around the pericardium etc.

The amphibians and reptiles feature dilated segments called the lymphatic hearts because of rhythmic contractions. These hearts feature muscular elements that force lymph. Some animals have up to 25 lymphatic hearts.

In birds and mammals, the lymphatic hearts persist only in embryonic period. The lymph vessels with valves appear instead. The valves and muscle fibers force lymph more effectively.

The lymph nodes first appear in birds. They form only two significant groups — the cervical and lumbar. In mammals, number of lymph nodes increases significantly. The lymph passed through the nodes reaches blood flow via only two principal ducts — the thoracic duct and the right lymphatic duct. Greater number of lymph nodes and vessels in mammals and humans ensures extensive protection of the organism.

Practice questions

1. What structural features allow differentiation of blood and lymphatic capillaries?
2. What parts are distinguishable in the thoracic duct?
3. Describe formation of the right lymphatic duct.
4. Name the lymphatic ducts.
5. Where do the lymphatic trunks and ducts open? Name the body regions drained by each trunk and duct.
6. Name the groups of lymph nodes situated on the border of head and neck.
7. What groups of lymph nodes reside within the cervical region?
8. Name the groups of parietal thoracic lymph nodes. Name the regions drained by these nodes.
9. Name the groups of visceral thoracic lymph nodes. Name the viscera drained by these nodes.
10. Name the groups of parietal abdominal lymph nodes.
11. Name the groups of visceral abdominal lymph nodes. Name the viscera drained by these nodes.
12. What lymph nodes receive lymph from the lesser pelvis viscera in part from the rectum?
13. What groups of lymph vessels are distinguishable in the upper limb? Name the destination point of these vessels.
14. What groups of lymph vessels are distinguishable in the lower limb? Name the destination point of these vessels.
15. What lymph nodes receive lymph from the breast?
16. Name the structures related to the primary and secondary organs. Explain your choice.
17. What populations of lymphocytes form the lymphoid tissue?
18. Discuss developmental and structural regularities of the lymphoid system.
19. Name the common morphological features of all secondary lymphoid organs.
20. What organs contain the lymphoid nodules?
21. Discuss structural features of the tonsils that from the pharyngeal lymphoid ring.

22. Discuss the structural features of the lymph node.
23. What structures of the lymph nodes pass lymph from the afferent vessels to the efferent?
24. What structural components of lymphoid tissue belong to the white pulp of spleen?
25. What animals are the first to develop the lymph vessels?
26. Describe the lymphatic recesses and lymphatic hearts in inferior vertebrates.
27. What animals are the first to develop the lymph nodes?

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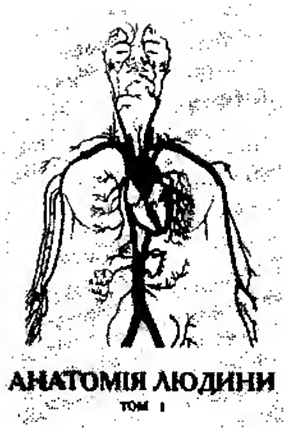

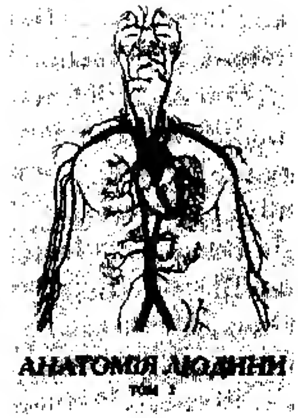

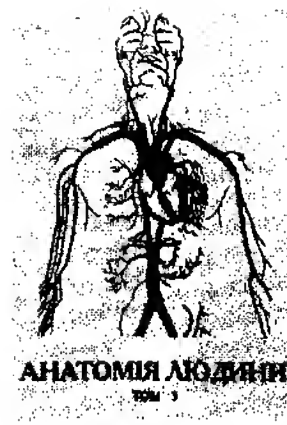

Учебник «Анатомия человека» издан под общей редакцией профессора В.Г. Ковешникова в трех томах на украинском и английском языках. Согласно решению Комиссии медицины научно-методического совета Министерства образования и науки Украины, он рекомендован Центральнымметодическимкабинетомвысшегомедицинскогообразования МОЗ Украины как учебник для студентов высших медицинских учебных заведений IV уровня аккредитации (протокол №1 от 12.04.2005 г.).

В предложенном учебнике по систематическому принципу изложены сведения нормальной анатомии человека в соответствии с современной программой для медицинских факультетов вузов (2002 г.).

В 2009 году ожидается издание учебника «Анатомия человека» на русском языке.

Для приобретения учебника, как трехтомником, так и отдельными томами, обращаться:

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Анатомія людини
В трьох томах
Том 3
(англійською мовою)

Підписано до друку 02.10.2009.
Формат 70x100/16. Папір офсетний. Друк офсетний.
Ум. друк. арк. 30,96. Обл.-видавн. арк. 43,81.
Наклад 10 000 прим. Зам. №145.
Ціна договірна.

Видавець і виготівник
ТОВ «Віртуальна реальність»
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Свідоцтво про внесення до Державного реєстру суб'єктів
видавничої справи ДК №1415 від 03.07.2003 р.

Віддруковано у видавництві «Максим»
91011, м. Луганськ, вул. Челюскінців, 16/а.
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Свідоцтво про внесення до Державного реєстру суб'єктів
видавничої справи ДК №3036 від 17.12.2007 р.